EVALUATION OF PRODUCTIVITY TRENDS IN THE SOUTH AFRICAN COAL MINING INDUSTRY

Anthea du Toit

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Engineering

Johannesburg, 2017

DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

……………………………………………………………………………………

Student: Anthea du Toit

Signed on this …31st….. day of …August……., …2017……

ABSTRACT

Productivity is an important topic within the mining industry and advances in productivity open up opportunities to make the best possible use of South Africa's mineral wealth. The report uses publicly available data to assess trends in productivity in the SA coal mining industry since the 1980s and to compare SA's performance with that of the US and Australia. It is found that between 1980 and 2003, productivity growth in the SA coal mining sector was primarily driven by capital deepening. However, productivity growth has been negative from 2004 onwards, despite continued capital deepening. Possible explanations include resource depletion, investment lags, deteriorating worker quality, increased complexity, more stringent safety regulations and adverse labour market conditions. The report highlights skills development and investment in innovation as possible ways of addressing declining productivity performance in the SA coal mining sector and recommends improvements to the availability of data for productivity research purposes.

ACKNOWLEDGEMENTS

I would like to thank Professor Bart van de Steen for his valuable research guidance. All remaining errors and omissions are my own.

Mr Martin Kohler of the Directorate: Mineral Economics at the Department of Mineral Resources kindly provided supplementary historical data and was exceedingly helpful in responding to my numerous data-related queries. Mr Johan Riekert of Quantec Research (Pty) Ltd provided kind assistance in explaining the compilation of the Quantec dataset.

I gratefully acknowledge financial assistance provided by Sasol Mining (Pty) Ltd during the course of my studies.

CONTENTS **Page**

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
BCM	bank cubic metres
CAGR	compound annual growth rate
DEA	data envelopment analysis
DMR	Department of Mineral Resources
GVA	Gross Value Added
KLEMS	capital-labour-energy-materials-services
LHD	load-haul-dump
MFP	multi-factor productivity
PPI	producer price index
RBCT	Richards Bay Coal Terminal
ROM	run-of-mine
SA	South Africa
SARB	South African Reserve Bank
TFP	total factor productivity
US	United States
US BLS	United States Bureau of Labour Statistics
US EIA	United States Energy Information Administration
US MSHA	United States Mine Safety and Health Administration

1 INTRODUCTION

Productivity is typically defined as the efficiency with which a firm, industry or country is able to convert inputs into output and is usually expressed as a ratio of output to inputs (Syverson, 2011: 329). Two of the most commonly used measures of productivity are labour productivity, measured as output per employee or output per hour worked, and total factor productivity (TFP), measured as output per combined unit of labour, capital, services and other inputs.

Why is productivity important? Productivity performance has a direct impact on the economic growth performance and welfare of a nation. According to mainstream economic theory, productivity growth is the key determinant of per capita income growth and rising living standards, and over longer timeframes the historical evidence supports this assertion (Steindel and Stiroh, 2001: 8). Similarly, on a microeconomic level, Syverson (2011: 327) highlights the robust empirical finding that more productive firms are more sustainable than their less efficient counterparts. As remarked by economist and Nobel laureate Paul Krugman: “Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker.” (Krugman, 1990: 11).

1.1 The global productivity growth slowdown

Following a prolonged downturn in global productivity growth in the 1970s and 1980s, worldwide productivity growth improved significantly from the mid-1990s until the mid-2000s. This was driven by the information and communication technology (ICT) revolution which was accompanied by significant investment in high-technology capital across all sectors of the economy (Steindel and Stiroh, 2001; Eichengreen et al, 2015).

The global financial crisis of 2007 and 2008 triggered a slowdown in productivity growth around the world, affecting advanced economies such as the United States (US) and United Kingdom, middle-income emerging markets such as China, Brazil and Mexico and lower-income regions including Sub-Saharan Africa, Central Asia, South-Eastern Europe and Latin America (Eichengreen et al, 2015: 2). The global productivity growth slowdown since the mid-2000s has been labelled "one of the most disturbing and important phenomena affecting the world economy" leading to some of "the critical debates of our day" (Eichengreen et al, 2015: 2; 13).

1.2 Productivity trends in the global mining industry

The mining industry has not escaped the worldwide trend of declining productivity. Globally, productivity in the copper-, aluminium-, iron ore- and coal mining industries has fallen since the mid-2000s, after nearly two decades of sustained productivity improvements. This had the knock-on effect of driving up production costs and prices for these commodities (Tilton, 2014: 1). The slowdown in global mining productivity was the direct result of the surge in commodity demand from China, which boosted commodity prices and encouraged the mining industry to seek higher production volumes at any cost (EY, 2014: 9).

After an initial correction in commodity prices coinciding with the global financial crisis of 2007 and 2008, commodity prices surged to record levels in 2011. Since 2011, however, commodity demand has slowed down significantly and this has had a negative effect on commodity prices and mining industry profits (McKinsey, 2015: 1). In response, mining companies have put productivity improvement and cost-cutting at the forefront of their business objectives. PwC (2014: 34) labels this "the productivity imperative" and notes that "productivity has become one of the most important topics as the (mining) industry aims to restore and sustain shareholder value". Although there have been signs of an improvement in mining productivity in recent years, productivity remains one of the top three risk areas according to mining executives (EY, 2016: 1).

Tilton (2014) highlights that innovation and new technologies can provide the means to achieve a turnaround in mining productivity. New digital technologies have proliferated and become more affordable in recent years. McKinsey (2015: 4) predicts that the mining industry landscape will be transformed by the application of digital technologies to improve knowledge of the resource base; optimise material and equipment flows; improve prediction of equipment failure; increase mechanisation and automation; and monitor real-time operational performance compared to plans.

1.3 The importance of productivity to SA coal mining

South Africa has a long history of coal production, starting in the 1870s when coal was first mined to supply energy to the diamond mining industry. The South African economy was built around coal as the dominant source of energy to fuel coal-fired power stations, railways and synthetic fuel production (Eberhard, 2011: 5). South Africa has a large coal resource base and coal is an integral part of the South African economy, providing approximately 70% of primary energy consumption, 93% of electricity and 30% of liquid fuels (Eberhard, 2011: 4). Coal is also one of the three largest commodity export earners, together with platinum and gold (Eberhard, 2011: 29).

While coal is expected to be gradually replaced by more sustainable and cleaner sources of energy, it will nonetheless remain a significant source of energy in SA for the foreseeable future. Eskom is continuing with the development of two new coal-fired power stations, Medupi and Kusile, and

Sasol has confirmed plans to extend the life of its coal-to-liquids operations until at least the year 2050 (Eskom, 2017; Sasol, 2014).
In the context of the South African (SA) coal mining industry, advances in productivity have the potential to considerably extend the life-of-mine of existing collieries. This will expand the country's coal resource base, presenting benefits to government in the form of tax revenue, employees in the form of employment and the community in the form of local economic development.

Moreover, by extending the life of SA collieries through enhanced productivity in the near- to medium-term, the SA coal mining industry retains the option to implement and benefit from future technological advances. This, in turn, opens up further opportunities to make the best possible use of SA's mineral wealth.

1.4 Purpose and research questions

The productivity performance of the SA coal mining industry has not been analysed in detail since the late 1990s. This is in contrast to other major coal producing countries, such as Australia and the US, where the literature has attempted to explain productivity performance of the coal mining sector since the 1970s (Topp et al, 2008).

The purpose of this study is to contribute to the literature by examining trends in SA coal mining productivity since 1980. The report aims to answer the following research questions:

- How should productivity be measured, what data are currently available to assess productivity performance and what are the shortcomings and measurement issues relating to SA mining productivity data?
- What are the key drivers of productivity in the SA coal mining sector?

- What has happened to productivity in the SA coal mining sector since the 1980s and how does SA coal mining productivity compare globally, in particular to developed countries with established coal mining sectors such as Australia and the US?
- How can the SA coal mining sector improve future productivity?

1.5 Methodology, scope and organisation of the report

The report uses an index approach to calculate productivity measures for the SA coal mining industry from 1980 to 2014. The analysis is done using publicly available data which was compiled by the author from a range of sources including a commercial data service, Quantec EasyData, and publicly available information from statistical agencies and regulatory bodies, including Statistics SA, the DMR and their counterparts in the US and Australia.

Labour productivity and TFP is estimated for the SA coal mining industry. Labour productivity growth is decomposed into TFP growth and changes in the weighted capital-labour ratio. SA coal mining labour productivity performance is also compared with labour productivity trends in Australia and the US. All tables and graphs in the report have been prepared by the author using the dataset and measures which have been derived, unless explicitly indicated otherwise.

The scope of the report has been limited to publicly available data. Where possible, the analysis has been performed for the full period from 1980 to 2014. However, in some instances the data was only available for shorter time periods. The analysis does not include data which is not in the public domain. For example, consulting company McKinsey have developed their MineLens Productivity Index, while PwC offers their Mining Equipment Productivity Index, both of which are proprietary databases of productivity measures derived from information obtained from individual mining operations (McKinsey, 2015; PwC, 2014).

Undoubtedly, the political, legal and regulatory environment has influenced investment in the SA coal mining industry, which in turn has had an effect on overall production levels and productivity measures. Similarly, in the US and Australia, political considerations have influenced the drive towards renewable energy which has resulted in mine closures in recent years. Assuming that more expensive, less productive mines are closed down first, this would have influenced coal mining productivity in these countries too. These issues, while important, have not been addressed in the report. It is left to other commentators to conjecture as to the possible counterfactuals, including for example what would have happened in the commodity boom years if policy uncertainty had not dampened mining investment in South Africa.

The remainder of this report is organised as follows:

- **Chapter 2** reviews key productivity concepts and the international and SA literature on productivity in coal mining;
- **Chapter 3** describes the methodology, approach, calculations and dataset used to estimate productivity measures;
- **Chapter 4** conducts a descriptive analysis to identify trends, outliers and potential measurement issues in the underlying data;
- **Chapter 5** calculates and analyses productivity measures for the SA coal mining sector;
- **Chapter 6** compares SA coal mining productivity with trends in Australia and the US; and
- **Chapter 7** summarises the findings, conclusions and recommendations of the report.

2 LITERATURE REVIEW

The literature review progresses from a general overview of productivity concepts, definitions and measurement, through to determinants of mining productivity, before moving on to specific studies of coal mining productivity in the US, Australia and SA. **Chapter 2** closes with a summary of the main conclusions that can be drawn from the existing literature and identifies key research questions.

2.1 Productivity concepts, definitions and measurement

Productivity can be measured in many ways, depending on the purpose of the measurement and the availability of data. Schreyer and Pilat (2001: 128) categorise productivity measures according to the choice of input variable (single- versus multi-factor productivity (MFP) measures) and the choice of output variable (gross output versus value-added[1]). **Table 2.1** summarises a number of commonly used productivity measures based on this classification. Schreyer and Pilat also provide an overview of the key conceptual and measurement issues which arise in the analysis of productivity trends over time and between countries. Two measurement issues which are particularly relevant to the mining industry are accurately measuring labour input and correctly determining the role of ICT in driving productivity growth (Schreyer and Pilat, 2001: 128).

[1] According to the OECD (2001), Gross Value Added (GVA) is defined as: “the value of output less the value of intermediate consumption; it is a measure of the contribution to GDP made by an individual producer, industry or sector; gross value added is the source from which the primary incomes of the SNA are generated and is therefore carried forward into the primary distribution of income account.”

Table 2.1 Overview of commonly used productivity measures

Type of output measure	Type of input measure: Labour	Capital	Capital and labour	Capital, labour and intermediate inputs
Gross output	Labour productivity (based on gross output)	Capital productivity (based on gross output)	Capital – labour MFP (based on gross output)	KLEMS MFP
Value-added	Labour productivity (based on value-added)	Capital productivity (based on value-added)	Capital – labour MFP (based on value-added)	–
	Single factor productivity measures		Multi-factor productivity (MFP) measures	

Notes:

- Source: Schreyer and Pilat (2001).
- KLEMS MFP is the abbreviation for Capital-Labour-Energy-Materials-Services MFP.

Labour productivity is the most commonly used measure since it is easily calculated using information that is readily available. However, as noted by Bartelsman and Doms (2000: 575), increases in labour productivity can result from increases in the capital-labour ratio without changing the underlying technology. While labour productivity is an appropriate concept for welfare comparisons, TFP provides more information about changes in technology and is the preferred measure in spite of difficulties in measuring capital service flows.

The nomenclature used in studies of productivity varies depending on the discipline of the author and the purpose of the analysis. The terms TFP and MFP are synonyms and can be used interchangeably[2]. The academic literature typically refers to TFP, while statistical agencies tend to use the

[2] In this report, the term TFP is used in the analysis (**Chapter 6**), while the literature review (**Chapter 2**) includes the terminology as per the cited work.

term MFP to acknowledge that it is not possible to include all (“total”) inputs in the calculation of productivity and that any calculation of productivity is based on assumptions regarding which inputs to include (Van Ark, 2014: 3).

2.2 Determinants of mining productivity

Tilton (2014) provides a useful framework for examining the determinants of mining productivity. Based on a review of the recent empirical literature, Tilton groups the determinants of productivity into eight categories, namely: innovation and technological change; resource depletion and resource quality; government regulations; worker quality; investment lags; economies of scale; capacity utilisation; and unplanned production stoppages (Tilton, 2014: 3). Tilton (2014: 6-7) also separately examines the impact of changes in commodity prices on mining productivity, which is included here as a ninth category.

2.2.1 Innovation and technological change

Technological change allows mines to become more productive by altering the production process. Technological change can take two forms. The first is embodied technological change, which is coupled with capital expenditures. In this way, new technology becomes “embodied” in the physical stock of capital. This can take the form of the introduction of progressively larger equipment in surface mining. It can also take the form of relatively small investments, which although not scale-enhancing, serve to reduce overall production costs.

The second form is disembodied technological change, which takes place without significant investment in capital. This can take the form of improvements in consumables, such as explosives, learning-by-doing, where firms become more efficient as they gain experience over time, or changes in management and work practices (Tilton, 2014: 3-4).

2.2.2 Resource depletion and resource quality

Natural resources can be viewed as an input to the production process, similar to capital or labour. As such, changes in the quality of the resource input will influence the quality and quantity of output and therefore productivity. Tilton (2014: 4) notes that the resource itself can be regarded as another input into the production process, where better quality reserves will result in higher productivity for a given level of labour, capital and other inputs.

As resources are generally depleted over time, with better quality, more easily accessible resources being mined out first, it is expected that productivity will decrease. In opencast coal mining, this may be represented by increasing strip ratios. In underground coal mining, this may take the form of narrower coal seams or more frequent occurrences of geological disturbances.

Although it is possible in theory to include resource quality in models of the production process, in practice it is difficult to obtain reliable estimates of resource quality. Most studies therefore omit resource quality as an explanatory variable and include it as part of the residual or unexplained portion of productivity (Tilton, 2014: 4).

2.2.3 Government regulations

Government policies, regulations and laws have an impact on productivity, mostly through their impact on labour input (Tilton, 2014: 4). For example, more stringent health and safety regulations may have a negative impact on productivity. Alternatively, the relaxation of stringent labour regulations may have a positive impact on productivity, by increasing the length of shifts or the length of the work week.

2.2.4 Worker quality

Worker quality, indicated by years of education or experience, has a direct impact on the labour input in the estimation of productivity. Although it is possible to adjust the labour input for changes in education levels, data on years of education is often not available and where it is available, does not take into account differences in the underlying quality of education (Tilton, 2014: 4).

2.2.5 Investment lags

Investment in mining capital typically takes place over a number of years, with normal production levels only reached once the mine has been fully developed. Mines may also undergo a process of debottlenecking before full production potential is realised. This means that productivity estimates will fall in the initial years following new investments in capital stock, with productivity only catching up later once full production capacity is reached (Tilton, 2014: 4).

2.2.6 Economies of scale

Economies of scale are evident where increases in production result in the distribution of fixed costs over a larger production base, thereby lowering the unit cost of output. For example, the increasing size of surface mines has raised productivity levels over the last 30 years.

However, increases in production beyond a certain optimal point may also result in diseconomies of scale, with each additional unit of output being produced at a higher marginal cost. Indeed, many “mega mines” have experienced declining productivity with the expansion of their operations in recent years, mainly due to the combination of increased complexity and a shortage of the skills required to manage this complexity (EY, 2014: 5).

In practice, however, Tilton (2014: 4) notes that the scale of a particular mining operation will be maximised, subject to geological and geographical constraints.

2.2.7 Capacity utilisation

Capacity utilisation has an impact on productivity by increasing or reducing the effective capital input to the production process. Since information on actual capacity utilisation is not collected by statistical agencies, studies of productivity usually rely on stock measures of capital and assume a constant rate of capital utilisation throughout the lifetime of capital. In practice, this will result in the over- or underestimation of actual productivity in periods of over- or underutilisation of capital (Tipper and Warmke, 2012: 7).

2.2.8 Unplanned production stoppages

Unplanned production stoppages due to labour unrest, safety incidents or accidents, equipment failures or adverse weather conditions will have a negative impact on productivity by reducing the availability of labour or productivity capacity (Tilton, 2014: 4).

2.2.9 Commodity prices

Tilton (2014) distinguishes between the long-term (“secular”) and short-term (“cyclical”) relationship between commodity prices and productivity. In the short-term, productivity fluctuates around its long-term trend in response to short-term commodity price fluctuations. When commodity prices are high relative to their long-term trend, mining productivity tends to fall below its long-term trend, and vice versa.

Tilton (2014: 5) explains this short-term relationship by referring back to the eight categories of mining productivity drivers. Two price effect channels, in particular, are highlighted by Topp et al (2008: xxi). Firstly, the effects of resource depletion and reserve quality are exacerbated during periods of higher commodity prices, since “existing operations can be continued longer than would otherwise be the case, previously mothballed mines can be reopened, and new mines that extract lower-quality, less-accessible and more-difficult deposits can come on stream” (Topp et al, 2008: xxi).

Secondly, higher commodity prices affect productivity through the capacity utilisation channel, since mines which are already operating at full capacity are pushed towards overcapacity, resulting in the less efficient utilisation of labour and intermediate inputs.

In the long-term, Tilton (2014: 7) notes that the causal relationship between productivity and prices can run both ways. On the one hand, changes in productivity related to resource depletion cause shifts in the long-run supply curve for commodities, which in turn impact on long-term commodity prices. However, commodity prices also influence the rate of innovation and technological change, which in the long-run feeds back to productivity. Tilton (2014: 7) notes that these two effects tend to offset each other, where technological advances spurred on by higher commodity prices result in productivity improvements which counteract the declines in productivity due to resource depletion.

2.3 Trends in US coal mining productivity

Ellerman et al (2001) examine productivity trends in the US coal mining industry between 1972 and 1995, using quarterly data on almost 20 000 individual coal mines taken from a database compiled by the US Mine Safety and Health Administration (US MSHA). By using this comprehensive dataset and employing a panel data approach, they are able to account for heterogeneity at mine level and uncover trends that would otherwise not be apparent at an aggregate level.

Ellerman et al (2001) measure productivity as quality-adjusted coal output (British thermal unit equivalent tonnes) per hour of labour input. Using this measure, they show that after an initial period of declining aggregate labour productivity between 1972 and 1978, labour productivity increased between 1978 and 1995, recording a net increase over the entire period. The magnitude of these trends depends on the level of aggregation used in the measure. For example, at the highest level of aggregation, labour productivity in 1995 was 2,7 times its 1972 level. However, after disaggregating the sample on the basis of region and mining method, labour productivity in 1995 was only 1,7 times the level in 1972 (Ellerman et al, 2001: 383).

Ellerman et al (2001) decompose changes in aggregate labour productivity over time into three different components or effects. Firstly, fixed (time-invariant) effects are mine-specific geological and technical characteristics factors, which vary across mines but stay constant over time, reflecting a base level of productivity for each mine. Secondly, time effects are factors which change over time and are likely to have a similar impact across mines, including regulatory changes, changes in input prices (wages) and changes in coal product prices. Finally, scale effects reflect the impact of the scale of operations on labour productivity.

Using this decomposition, Ellerman et al (2001) find that the decline in labour productivity in the 1970s can largely be attributed to rapidly rising coal prices while labour input costs grew at a slower rate. This is captured as part of the time effect in their model. In this context, mines were more inclined to “throw labour and other inputs at the coal face” to increase aggregate production, which had a negative impact on labour productivity. To a lesser extent, more stringent mine health and safety regulations also contributed to the decline in productivity during this period (Ellerman et al, 2001: 404-405).

Ellerman et al (2001: 406) ascribe rising productivity during the 1980s and 1990s to three factors. The first is mine fixed effects, where the introduction over time of newer mines with more productive technology resulted in a persistent improvement in productivity. Indeed, these effects are found to have been in operation during the 1970s also, although they were negated by the price effect. The second factor is a price effect, where a drop in the price of coal triggered a reversal of the 1970s trend and encouraged mines to economise on labour inputs. The third factor is scale effects, where the development of increasingly larger mines and debottlenecking over time had a positive impact on productivity.

Stoker et al (2005) build on the analysis of Ellerman et al (2001) by performing a number of additional diagnostic tests using the same dataset. The earlier results appear to be robust to alternative specifications and estimation methods. They go on to highlight that despite fluctuations in aggregate labour productivity over time, technical progress, as measured by the fixed effects component, showed a consistently increasing trend over time.

2.4 Trends in Australian coal mining productivity

Three studies of Australian coal mining productivity are included in the review, namely Topp et al (2008), Lovell and Lovell (2013) and Takahashi (2011).

2.4.1 Impact of resource depletion and investment lags

Topp et al (2008) provide a long-term view of productivity in the Australian coal mining sector between 1974/75 and 2006/07, using data from the Australian Bureau of Statistics (ABS). Productivity is measured in terms of value added-based MFP, which is calculated by weighting labour and capital inputs together using estimates of relative payments to capital and labour.

The output measure (value added) is calculated using data on gross output and purchases of material and services. Labour input is measured as the number of employees and capital capacity is estimated from data on annual expenditure on machinery and equipment and non-dwelling construction (Topp et al, 2008: 139-140).

Topp et al (2008) focus on the impact of resource depletion and investment lags as determinants of productivity. In order to test the effects of resource depletion, they use changes in the ratio of saleable to raw coal as a proxy for changes in the quality of coal and incorporate this measure into their MFP calculation. The saleable to raw coal ratio is calculated using data from Mudd (2007) and the Australian Bureau of Agricultural and Resource Economics (ABARE) (Topp et al, 2008: 57-59).

In order to test the investment lags hypothesis, MFP is re-estimated using an index of capital input that is lagged three years, which is then compared to MFP estimated using contemporaneous capital input. The choice of a three year lag length is based on an evaluation of the average construction time of new mining projects as indicated by ABARE data (Topp et al, 2008: 77-78).

Topp et al (2008: 115) find that MFP in the coal mining industry has steadily increased since the 1980s, reaching a turning point in the early 2000s. The increase in coal mining productivity is part of a broader trend of technological advancement and improved management practices in the Australian mining sector since the 1960s. In coal mining, advancements have included the expansion of opencast- and longwall mining methods and increases in the scale and automation of mining operations and equipment (Topp et al, 2008: 113). Between 2000/01 and 2006/07, MFP declined by almost 25 per cent, which they attribute to a substantial increase in labour and capital inputs combined with a modest increase in output.

Topp et al (2008) break down the overall 24,5 per cent decline in MFP into three main components. They find that resource depletion had only a marginal effect on MFP, explaining 3,8 per cent of the decline between 2000/01 and 2006/07. The effect of investment lags in capital was much more pronounced and contributed a further decline of 27,7 per cent in MFP. After controlling for both the resource depletion and investment lag effects, they find that MFP in the coal mining industry actually increased by 7,1 per cent between 2000/01 and 2006/07 (Topp et al, 2008: 116-117).

Given that the decline in MFP is mostly explained by investment lag effects, which are temporary in nature, Topp et al (2008: 115) predict that MFP will improve once all new coal mines and mine expansions reach full production.

Topp et al (2008: 57) acknowledge that the growing overburden ratio in the Australian coal mining industry is likely to have had a significant impact on productivity since the 1980s. Indeed, they note that the detrimental effect of higher overburden ratios is likely to have been much greater than the effect of changes in the quality of coal. In order to shed light on this issue, they recommend that further work is undertaken to investigate the impact of overburden ratios on unit costs of coal mining production.

Lovell and Lovell (2013) test the findings of Topp et al (2008) to confirm the magnitude of the decline in value added MFP of the Australian coal mining sector between 2000/01 and 2006/07. They apply the same methodology as Topp et al (2008), but use a revised dataset. They also use an alternative weighting methodology for the calculation of MFP.

Lovell and Lovell (2013: 451) conclude that Australian coal mining productivity has been driven by resource depletion. However, this explains only a small portion of the overall measured productivity decline between 2000/01 and 2006/07. Although the capital lag effect is found to have merit, they highlight that this finding depends crucially on the underlying assumption regarding the rate of capacity utilisation. Estimates of capital services in the coal mining industry are also subject to mismeasurement (Lovell and Lovell, 2013: 452).

Lovell and Lovell (2013) note that factors such as regulatory changes, skills shortages, delays in equipment delivery and production interruptions related to adverse weather conditions are likely to have played an equally important role in explaining productivity trends during this period. Unfortunately, these excluded variables are difficult to measure and incorporate into empirical explanations of productivity change (Lovell and Lovell, 2013: 452).

2.4.2 Impact of multi-tasking

Takahashi (2011) applies a micro-level approach to analyse coal mining productivity, using a dataset consisting of 21 Australian surface mines for the period 1985 to 2005. In particular, he assesses the impact of the introduction of multi-tasking, which is assumed to have had a productivity enhancing-effect on the Australian coal mining sector (Takahashi, 2011: 842).

Takahashi (2011: 849) models Australian coal mining industry productivity using a production function specification, where individual coal mining output is defined as the sum of labour inputs and capital inputs at each individual mine. The model includes two variables intended to capture the effects of multi-tasking between production and engineering streams and multi-tasking within the production stream. The model also includes a range of control variables and allows for time-invariant fixed effects (Takahashi, 2011: 850).

Takahashi (2011) estimates the model using fixed effects estimation methods and tests the robustness of his results using instrumental variables and two-stage least squares procedures, instrumenting the multi-tasking variables with coal quality data. In order to estimate the model, he constructs a detailed dataset which collates information from a range of sources, including government departments, industrial boards and registries, external data providers and equipment manufacturers (Takahashi, 2011: 851).

Output is measured in terms of saleable coal production and labour input is measured as the number of employees. Capital inputs are measured by bulldozer usage (the sum of engine capacities), truck usage (the sum of loading capacities) and excavator usage (the sum of bucket sizes). Other control variables include seam thickness, ownership by oil majors and

Japanese ownership (Takahashi, 2011: 849). He also includes a range of work practice variables, which are derived from an analysis of the underlying enterprise agreements, and are intended to separate the effect of multi-tasking from other changes in work practices.

Takahashi (2011: 856) finds that the introduction of multi-tasking between the production and engineering streams had a large effect on productivity, explaining up to a third of the variation in productivity at mine level. However, multi-tasking within the production stream did not have a significant productivity impact. He concludes that the positive impact of multi-tasking was most likely the result of the elimination of redundancies in effort and wait-time (Takahashi, 2011: 860).

2.5 SA studies of coal mining productivity

Only a handful of studies have examined productivity in the SA coal mining sector. Four of these, namely Jones (1983), Fine (1992), Hardman (1996) and Moolman and Fourie (2000) are reviewed here. Internet searches and academic journal database queries conducted by the author using “productivity”, “coal mining” and “South Africa” as search terms failed to retrieve any detailed study of coal mining productivity in SA since the late 1990s.

2.5.1 SA coal mining productivity between 1950 and 1980

An early example is Jones (1983), which evaluates TFP growth in the SA coal mining industry between 1950 and 1980 using data from Statistics SA (then Central Statistical Services), the SA Reserve Bank (SARB), the Department of Mineral Resources (DMR) (then Department of Mineral and Energy Affairs) and the Chamber of Mines.

Coal industry output is measured as tonnes of saleable coal produced, while labour input is measured as the number of employees. In conjunction with labour input, he also takes into account measures of capital and raw materials to develop an index of total factor input.

Jones (1983) uses three different weighting procedures to derive an estimate of coal mining TFP, finding that productivity in the coal mining industry was only 10 per cent higher in 1980 than 30 years earlier. He further subdivides the three decades into five distinct sub-periods and correlates these with the implementation of new extraction technologies (refer **Table 2.2**).

The first major wave of mechanisation started in the 1950s but only gathered momentum in the 1960s, with the replacement of simple hand-got mining methods by conventional mining using load-haul-dump (LHD) machinery. SA coal mining conditions were perceived to be comparable to those in the US and therefore amenable to mining using LHDs. As a result of the introduction of LHDs, the coal mining industry went through a protracted period of learning, which explains the negative trend in overall TFP until the late 1960s (Jones, 1983: 346).

By 1974, approximately 60 per cent of all coal in SA was produced by conventional mining using LHD machinery, compared to less than 10 per cent in 1950.

Table 2.2 Five TFP growth periods in the SA coal mining industry

Period	Period	Duration (number of years)	Annual TFP growth rate (percentage)
1. Familiarity: Hand-got	1950 to 1958	8	1,3
2. Learning: Conventional LHD	1959 to 1967	9	-1,0
3. Familiarity: Conventional LHD	1968 to 1974	7	2,2
4. Learning: Opencast-, Longwall- and CMs	1975 to 1978	4	-4,1
5. Familiarity: Opencast-, Longwall- and CMs	1979 to 1980	2	5,3
Overall	1950 to 1980	30	0,3

Table adapted from Jones (1983).

The mid-1970s coincided with a period of further mechanisation, with the adoption of opencast-, continuous mining- and (to a lesser extent) longwall mining methods. This round of learning lasted only four years, with TFP growth once again becoming positive by the end of the 1970s (Jones, 1983: 346; 348).

The adoption of new technologies in the 1970s was driven by rapidly rising global demand, which led to a steep increase in the price of coal. At the time, SA was becoming a major player in the seaborne thermal coal market through the development of the Richards Bay Coal Terminal (RBCT). A number of new collieries were also established during this period to support the expansion of Eskom’s fleet of coal fired power stations (Mohring, 2012: 789).

The drive towards more capital-intensive mining methods may also have been driven by incidences of labour unrest at a number of collieries in the Witbank area during the 1970s (Spandau, 1980: 111).

Fine (1992) revisits the analysis of Jones (1983) and argues that productivity in the SA coal mining sector grew significantly between 1950 and 1980, with labour productivity in 1980 reaching almost 2,5 times its base level. Fine (1992) relates the increase in labour productivity to the increasing intensity of capital and raw material use during this period. He argues that the SA coal mining industry displayed evidence of economies of scale during this period, a trend which further accelerated during the 1980s (Fine, 1992: 167).

Fine (1992) criticises Jones' (1983) analysis on a number of points, with his main criticism relating to the choice of TFP as productivity measure. Fine (1992) contends that the underlying assumptions used in the derivation of TFP, in particular the assumption of perfectly competitive markets, did not hold in the SA coal mining industry between 1950 and 1980 (Fine, 1992: 171).

Fine also challenges the choice of output measure, arguing that the output measure should be adjusted for differences in quality to take into account the changing composition of coal sales during this period. By 1980, SA high-value coal exports had grown from almost zero a decade before to almost 30 million tonnes per annum. As such, Jones' (1983) analysis of TFP was likely to understate productivity growth (Fine, 1992: 168).

2.5.2 SA coal mining productivity between 1985 and 1995

Hardman (1996) uses information from the DMR (then Department of Mineral and Energy Affairs) to compare the productivity performance of the SA coal mining sector to the performance of the Australian and US coal mining sectors between 1985 and 1995.

Hardman (1996) distinguishes between output from surface operations and output from underground operations to highlight differences in productivity between these two mining methods. Hardman (1996: 299) notes that, all else being equal, surface mining methods tend to be more productive compared to underground mining methods. Similarly, longwall underground mining methods are more productive than bord and pillar underground mining methods. As such, differences in the underlying composition of output in terms of mining method between SA, the US and Australia is likely to explain differences in productivity between these countries.

While surface mining methods were in use at the majority of coal mining operations in Australia (71 per cent of total saleable production) and the US (59 per cent of total saleable production), it only contributed 45 per cent of total saleable coal mining output in SA. In addition, output from longwall mining methods was higher in Australia (two thirds of total saleable production from underground mines) and the US (one third of total saleable production from underground mines) compared to SA, where output from longwall mining methods only constituted 13 per cent of total underground saleable production (Hardman, 1996: 298).

Hardman (1996) finds that all three countries experienced an increase in coal mining output (measured in saleable tonnes) and a decrease in labour input (measured in man years) between 1985 and 1995, which resulted in increasing labour productivity (measured in saleable tonnes per man year) during the period. The US experienced the greatest labour productivity growth over the period, recording an increase of 113 per cent to 9 025 tonnes per man year in 1995. Australia recorded a labour productivity growth rate of 83 per cent over the same period, achieving productivity of 7 564 tonnes per man year in 1995.

SA recorded labour productivity growth of 128 per cent during this period. However, this was from a low base, so that productivity in 1995 was only 3 316 tonnes per man year, or 40 per cent of the US and Australian average. Hardman notes that despite their relative underperformance in productivity terms, SA coal mining operations were able to remain globally competitive on the basis of lower labour costs (Hardman, 1996: 299-300).

2.5.3 Benchmarking SA coal mining productivity performance

Moolman and Fourie's (2000) productivity benchmarking study represents an important contribution to the literature and provides a detailed micro-economic view of productivity at SA surface coal mines. Under the auspices of the Coaltech 2020 Research Programme, a data gathering exercise was undertaken which covered nine SA surface mines.

Mine-specific data for the 1997/1998 financial year were gathered in the form of a comprehensive questionnaire, which was completed for each mine in the sample. The SA coal mines were benchmarked against a sample of two US and four Australian surface coal mines, which had been selected on the basis of their world-class productivity performance (Moolman and Fourie, 2000: 20).

Moolman and Fourie (2000) calculate measures of labour productivity, capital productivity and total productivity using a range of output and input measurements. Output is measured in terms of total bank cubic metres (BCMs) mined and ROM coal tonnes mined. Labour input is measured in man years, which is based on hours worked, and includes both permanent employees and contractors (Moolman and Fourie, 2000: 23; 80). Capital input is measured as the reported capital invested in mining equipment and includes work-in-progress, repair and replacement costs, rehabilitation costs and overhead costs (Moolman and Fourie, 2000: 54).

Moolman and Fourie (2000) find that SA labour productivity as measured in terms of average ROM tonnes per man year was the lowest of the participating benchmark mines, with labour productivity nearly nine times lower than the US industry leader. Total BCMs per man year of SA mines also lagged behind its international counterparts.

To a certain extent, this reflects the more labour intensive nature of the SA mining industry relative to those of the US and Australia, which are more capital intensive. SA surface mines also use relatively smaller pieces of equipment, which increases the labour requirement (Moolman and Fourie, 2000: 27).

Moolman and Fourie (2000: 28) highlight the impact of lower annual available operating hours in SA relative to the US and Australia. Most of the SA mines included in their survey operated on a six-day work week, compared to international best practice mines which work on a full calendar principle. In addition, the SA mines which were surveyed did not report normal production for the eleven official public holidays (which have subsequently increased to twelve).

This is in contrast to US and Australian mines, which continue to produce irrespective of public holidays. According to the estimates of Moolman and Fourie (2000: 29), the combined effect of hours lost due to the six-day work week and public holidays is to reduce the annual available hours on SA coal mines by over 17 per cent.

Capital productivity at SA surface mines, as measured in BCM units per unit of mining capital invested, was only two thirds of the capital productivity achieved at international benchmark mines (Moolman and Fourie, 2000: 30). They conclude that the lower relative capital productivity can be linked to lower labour productivity, lower operating hours, longer haulage distances, longer truck spotting times and the use of smaller equipment (Moolman and Fourie, 2000: 35).

Moolman and Fourie (2000: 37) also highlight the impact of less favourable geological conditions in SA compared to international benchmarks. In particular, thinner multiple coal seams often do not justify the installation of in-pit crusher conveyor systems, which would lower average haulage distances between pits and coal tips.

2.6 Summary and conclusions from literature review

The literature review confirmed that while there are a number of different ways to measure coal mining productivity, most of the studies reviewed in this report follow broadly similar approaches:

- Most studies analyse labour productivity or TFP, with one study (Moolman and Fourie, 2000) also analysing capital productivity;
- Most studies use gross output measured in production tonnes to calculate productivity, with only one study (Topp et al, 2008) using value added as output measure; and
- Most studies include labour and capital as input measures, while some studies also include measures of resource depletion (Topp et al, 2008), work practices (Takahashi, 2011) and raw materials (Jones, 1983) as input measures.

Long-term trends in coal mining productivity were similar across the three coal mining jurisdictions covered in the literature review. Innovation and technological change played an important role in driving productivity in the US, Australia and South Africa, particularly during the 1980s and 1990s:

- In the US, coal mining productivity declined in the 1970s mainly due to rapidly rising prices and more stringent regulations. From the late-1970s to the mid-1990s, US coal mining productivity increased again, due to innovation and technological change, price decreases and economies of scale.

- In Australia, coal mining productivity increased from the mid-1970s to 2000, driven by technological change and economies of scale. The introduction of multitasking, which is another form of innovation and technological change, also played a role in boosting productivity during this period. Since 2000, Australian coal mining productivity has declined, mainly due to investment lags and resource depletion. Other factors which may have contributed to the decline since the 2000s include regulatory changes, skills shortages, delays in equipment delivery and adverse weather.
- In South Africa, coal mining productivity increased from 1950 to 1980 as new mining technologies were introduced, leading to greater capital intensity and increased economies of scale. While productivity continued to grow significantly between 1985 and 1995, labour productivity in the South African coal mining sector remains at around 40 per cent of the US and Australian average. This is partly due to geological conditions which are more amenable to underground mining relative to surface mining methods and continuous mining relative to longwall mining methods. South African coal mines also have larger labour requirements due to smaller operating equipment and lower annual operating hours.

With only a few studies examining productivity in the SA coal mining sector, and no studies done since the late 1990s, the following questions arise:

- What has happened to SA coal mining productivity since the late 1990s and particularly during the mining boom of the 2000s?
- What are possible explanations of productivity trends in the SA coal mining industry since the late 1990s?
- How has South African productivity fared relative to the US and Australia during this period?

The remainder of the research report aims to address these questions by calculating and analysing productivity measures for the SA coal mining sector using publicly available information published by statistical agencies and regulatory bodies.

3 METHODOLOGY

Chapter 3 provides an overview of different approaches to estimating TFP. It goes on to describe a simple model of production which forms the basis of the index approach which was used to derive the productivity estimates in **Chapter 5** of this report. It also provides the calculations which were used to estimate labour productivity, TFP and the capital-labour ratio as well as the functional relationship between these three measures.

3.1 Approaches to estimating TFP

There are two broad approaches to measuring TFP, differentiated by the way in which output elasticities[3] are estimated.

The non-parametric[4] or index approach that is followed in this study and outlined in **Chapter 3.2**, makes a number of simplifying assumptions that allow for the direct calculation of output elasticities using data that is readily available (Syverson, 2011: 332).

Another approach is to specify a production function and estimate the output elasticities using econometric methods. While the parametric approach allows for greater flexibility, it raises a number of econometric issues as highlighted by Syverson (2011: 332). Many of these issues can be overcome if a sufficiently rich dataset consisting of a panel of output data with observations for a number of firms each observed over several years is available (Greene, 2003: 284). This is the approach followed by

[3] Output elasticity is defined as the ratio between the proportional change in output resulting from a proportional change in an individual input, such as capital, labour or intermediate goods.

[4] Other non-parametric approaches such as data envelopment analysis (DEA) are also used to study productivity in the academic literature, but not discussed here. Syverson (2011: 331) provides references for an overview of DEA methods.

Ellerman et al (2001) and Stoker et al (2005) using the US MSHA database. Unfortunately, this type of data is not currently available for the SA coal mining industry, as further discussed in **Chapter 6.6** of this study.

3.2 Theoretical model of production

The traditional growth accounting or index approach originally developed by Solow (1957) is used to derive productivity measures in this report. The index approach starts with a simple two-factor Cobb-Douglas production function specification:

$$Y = AK^{\propto}L^{1-\propto} \tag{1}$$

where

Y = output;

K = capital input;

L = labour input;

A = cumulative effect of technical change; and

$0 < \propto < 1$.

The Cobb-Douglas production function assumes an elasticity of substitution of exactly 1, implying that capital and labour are perfect substitutes. It also assumes constant returns to scale and perfect competition so that $\propto$ equals capital's share in total income. Technology enters the model in the output-augmenting or Hicks-neutral form, which means that it raises the maximum level of output that can be produced with a given level of inputs without changing the relationship between the different inputs.

Applying a logarithmic transformation and taking the total differential with respect to time gives:

$$\ln\left(\frac{Y_t}{Y_{t-1}}\right) = \ln\left(\frac{A_t}{A_{t-1}}\right) + \propto \left(\ln\frac{K_t}{K_{t-1}}\right) + (1-\propto)\left(\ln\frac{L_t}{L_{t-1}}\right) \qquad (2)$$

where the growth rate of output on the left side of the equation equals the sum of the rate of technical change, the weighted growth rate of capital and the weighted growth rate of labour.

By assuming a perfectly competitive market, each factor of production earns its marginal product, so that the elasticities of output with respect to capital and labour $\propto$ and $(1-\propto)$ can be measured using data on the share of income going to capital and labour. In practice, labour's share in total income is straightforward to collect using labour remuneration data. Capital cost measures are more problematic to compile, so it is easier to construct capital's share in income as the residual (Syverson, 2011: 332).

3.2.1 Calculation of labour productivity

This report follows the approach outlined by the US Bureau of Labour Statistics to calculate a labour productivity index by dividing an index of industry output by an index of industry labour input (US BLS, n.d.: 2). The labour productivity index is calculated as:

$$\frac{Y_t}{Y_0} \div \frac{L_t}{L_0} \qquad (3)$$

where

$\frac{Y_t}{Y_0}$ = the index of output in the current year;

$\frac{L_t}{L_0}$ = the index of labour input in the current year;

t = the current year; and

0 = the base year.

3.2.2 Calculation of TFP

TFP is calculated in this report by rearranging equation 2 and changing the cost share notation slightly and then calculating the difference between the growth rate of output and the growth rate of a Tornqvist index of capital and labour:

$$\ln\left(\frac{A_t}{A_{t-1}}\right) = \ln\left(\frac{Y_t}{Y_{t-1}}\right) - \left[w_k\left(\ln\frac{K_t}{K_{t-1}}\right) + w_l\left(\ln\frac{L_t}{L_{t-1}}\right)\right] \qquad (4)$$

where

$\ln$ = the natural logarithm of the variable;

A = TFP;

Y = output;

K = capital input;

L = labour input; and

w_k and w_l = input cost share weights.

The input cost share weights are calculated as:

$$w_l = \frac{(s_{l,t} + s_{l,t-1})}{2} \qquad (4.1)$$

$$w_k = 1 - w_l \qquad (4.2)$$

$$s_{l,t} = \frac{p_{l,t}\, x_{l,t}}{p_{l,t}\, x_{l,t} + p_{k,t} x_{k,t}} \qquad (4.3)$$

$p_{i,t}$= price of input x_i in period t

so that the input cost share weights are two-year averages of the cost shares of capital and labour. In order to calculate the cost share for labour in equation 4.3, labour remuneration at current prices is used as the numerator, while gross value added (GVA) at current prices is used as the denominator. The cost share for capital is derived as a residual.

By rearranging equation 4, labour productivity can be related back to TFP:

$$\ln\left(\frac{Y_t}{Y_{t-1}}\right) - \ln\left(\frac{L_t}{L_{t-1}}\right) = \ln\left(\frac{A_t}{A_{t-1}}\right) + w_k\left[\ln\left(\frac{K_t}{K_{t-1}}\right) - \ln\left(\frac{L_t}{L_{t-1}}\right)\right] \quad (5)$$

where the growth rate of labour productivity on the left hand side of the equation equals the growth rate of TFP plus the effect of changes in the weighted capital-labour ratio, also known as capital deepening (US BLS, n.d.: 6).

3.3 The dataset

The productivity measures which are described in **Chapter 3.2** were calculated as part of the research report using a dataset which was put together by the author from a range of different sources. The dataset was compiled using a commercial data service (Quantec EasyData) and this was supplemented with publicly available information which was obtained from statistical agencies and regulatory bodies, including Statistics SA, the DMR and their counterparts in the US and Australia. The productivity measures which were calculated by the author from the dataset are reported and analysed in **Chapters 4, 5 and 6**.

3.3.1 Quantec dataset

The main body of the analysis was performed using annual time-series data for the SA coal mining industry (SIC 21) obtained from Quantec EasyData's Standardised Industry database. EasyData is a subscription service from Quantec that provides users with online access to a comprehensive collection of South African and global socio-economic and market indicators. The Quantec database combines a comprehensive set of industry and national account indicators with a consistent input-output framework and is derived from official statistics sourced from Statistics SA (Quantec, 2015).

All of the variables in the Quantec dataset were available from 1970 to 2014, except for saleable production, which was available from 1980 onwards. The analysis therefore focuses on the 34-year period between 1980 and 2014.

Input and output data

The analysis uses data on labour input (number of employees and labour remuneration), capital input (fixed capital stock and gross operating surplus), output (saleable production and GVA) and prices (export sales and local sales) from the Quantec database.

Quantec's data on the number of employees, labour remuneration and saleable production is based on the P0271, P0277 and P2041 statistical releases from Statistics SA, which in turn is compiled from the B1 statistical tables generated by the DMR.

Saleable production tonnes is defined as raw production tonnes minus waste or discards. The Quantec dataset only includes data on saleable production tonnes, not raw production tonnes. The evaluation of long-term SA productivity trends in **Chapters 5** and **6** has been based on saleable production tonnes, since the Quantec dataset covers a longer timeframe, while the comparison of SA productivity with global peers in **Chapter 7** was done on the basis of raw production tonnes.

Skills data

The data on the number of employees is further broken down by skills level, which is derived from occupational data from the Quarterly Labour Force Surveys and census data published by Statistics SA. The highly skilled category includes managers, professionals and technicians. The skilled category includes clerks and plant- and machine operators. The semi- and unskilled category includes all occupations which do not fall into the first two categories, consisting mainly of elementary occupations (Statistics SA, 2014: 1).

3.3.2 Supplementary data from the DMR

The Quantec data was supplemented with monthly data on the average number of shifts worked in the coal mining industry and annual production data categorised by mining method, which was kindly provided to the author by the Directorate: Mineral Economics of the DMR.

Production by mining method

The DMR distinguishes between four different mining methods in the compilation of its production data, namely opencast, bord and pillar, stooping and longwall. The last three categories have been combined in the analysis and are reported as underground mining methods.

The DMR's annual production data was made available on a raw (run-of-mine or ROM) basis from 2006 until 2014. **Chapter 6** makes use of the DMR's raw production data to compare SA's productivity performance with its peers[5].

Shifts worked

The DMR compiles the shifts worked data from mine health and safety information, which forms part of the mandatory reporting by all operating coal mines in SA. The shifts worked data was made available for the period between January 2005 and December 2014.

---

[5] The US Energy Information Administration (US EIA) reports coal production data on a raw basis only, while the Australian Department of Industry, Innovation and Science reports both raw and saleable coal production. To ensure comparability between the three jurisdictions, **Chapter 7** is based on raw coal production data.

The DMR data on shifts worked are reported by SA mines based on clock card hours registered at the mine gate. Individual mines measure the total number of hours in the risk situation during a particular month and then divide total hours by a number ranging between 8 and 12 to get to the total number of shifts worked during the month[6]. The total number of shifts worked in a month is then divided by the number of normal working days in the month to get to the measure of average shifts worked as reported to the DMR[7].

The DMR's monthly data on shifts worked were used as the basis to calculate an annual measure of hours worked in the SA coal mining industry. For each calendar year, the monthly shifts worked data was averaged to get to the mean number of shifts worked per normal working day during the year. A total of 275 working days per annum was assumed, taking into account a calendar year of 365 days with Sundays off (52 days), every second Saturday off (26 days) and 12 public holidays. Assuming an average shift length of 8 hours, this gave a conversion factor of 8 x 275 = 2 200 hours per annum to convert the annual average shifts worked data to annual average hours worked data.

3.3.3 Other data sources

Export and local sales prices were deflated using Statistics SA's Producer Price Inflation (PPI) series for domestic output of SA industry groups up to 2012 and the PPI series for final manufactured goods after 2012.

[6] Shift lengths vary between mines, depending on the particular shift system in operation, but typically range between 8 and 12 hours per shift.

[7] The normal number of working days is also not defined and varies between mines.

Data on average annual Rand/US$ exchange rates for the period 1971 to 2014 was obtained from the website of the Board of Governors of the Federal Reserve System[8].

Supplementary data on the number of workdays lost due to strikes and lockouts per 1 000 workers for the period 1998 to 2014 were obtained from the ILOSTAT database of the International Labour Organisation (International Labour Office, 2016).

Data on raw coal production and the number of coal mining employees in Australia and the US was obtained from the websites of the US Energy Information Administration (US EIA, 2016) and the Australian Department of Industry, Innovation and Science (2016b). The US raw coal production data was converted from short tons to metric tonnes using a conversion factor of 0,907184.

Data for SA and the US is reported by Statistics SA and the US EIA on a calendar year basis, while the Australian Department of Industry, Innovation and Science reports data with 30 June as year-end. The Australian data was incorporated into the analysis by shifting the year-end ahead to December, e.g. 06/07 is reported as 2007, 07/08 is reported as 2008, and so forth[9].

[8] http://www.federalreserve.gov/

[9] By shifting the Australian data ahead, this may introduce an artificial lag effect of six months for Australia compared to SA and the US. However, given the long timeframes typically involved in mining production and investment, this effect is expected to be negligible.

4 DESCRIPTIVE ANALYSIS

Chapter 4 examines trends in coal mining output and the two traditional input measures, namely capital and labour input, to identify trends, outliers and potential measurement issues in the underlying data. It also examines other determinants of productivity in the coal mining industry, namely the skills composition of the labour force, underlying mining methods and trends in coal sales prices.

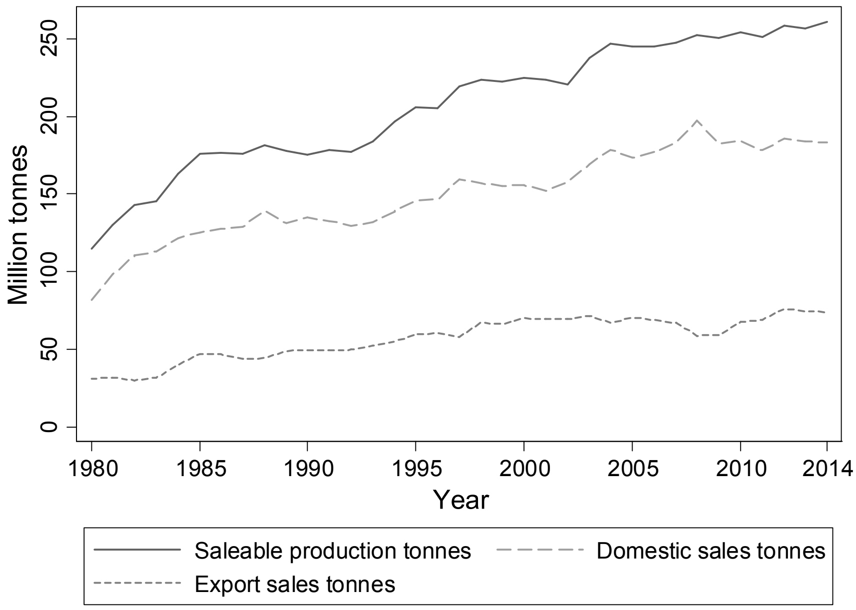
As noted in **Chapter 2.2**, coal mining productivity may also be influenced by a number of other factors. However, the analysis here has been limited to factors for which data is readily available. Other factors, such as resource depletion and resource quality, government regulations, investment lags, economies of scale, capacity utilisation and unplanned production stoppages are not discussed here.

4.1 Output measures

Two output measures were examined, namely saleable production tonnes and GVA.

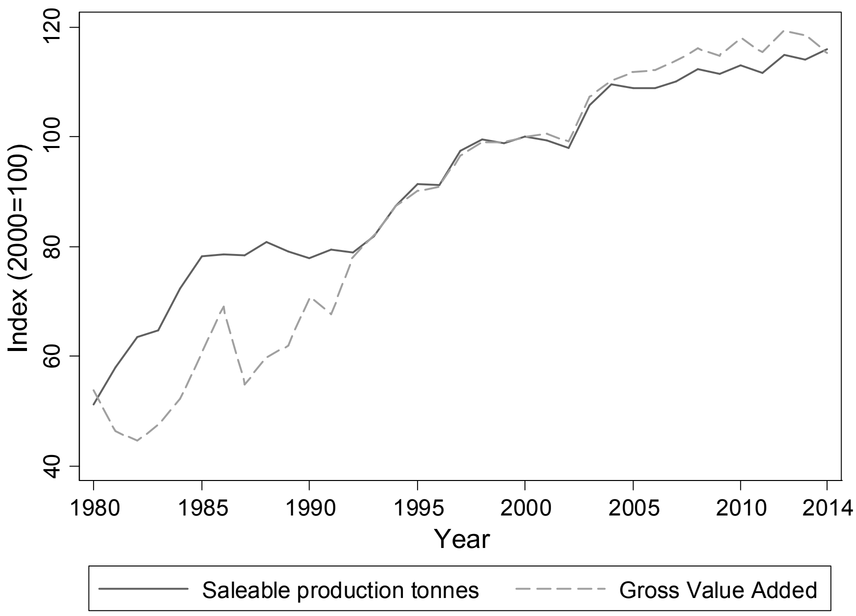
4.1.1 Total saleable coal production

As shown in **Figure 4.1**, saleable coal production volumes increased from an initial level of 115 Mt in 1980 to around 175 Mt in 1985 and remained at this level until the early 1990s. Between 1992 and 1998, production again increased to 220 Mt, almost doubling the initial level of production in 1980. The increase in coal production during the 1980s and 1990s reflects Eskom’s rapid expansion during this period.



Source: Quantec (2015)

Figure 4.1 Saleable production, domestic sales and export sales



Source: Quantec (2015)

Figure 4.2 Saleable production tonnes and GVA

The Tutuka and Lethabo coal-fired power stations were commissioned between 1985 and 1990, the Matimba and Kendal power stations were commissioned between 1988 and 1993 and the Majuba power station was commissioned between 1996 and 2001 (Eskom, n.d.). At the same time, expansions at the RBCT supported growth in export sales, growing from an initial capacity of 12 Mtpa in 1981 to a capacity of 63 Mtpa by 1995 (RBCT, n.d.).

Saleable coal production volumes stabilised again in 1998 and remained relatively flat until 2002. Following an initial jump in saleable coal production in 2003 and 2004, production continued to increase steadily during the 2000s, albeit at a slower rate than experienced during the expansionary periods of the 1980s and 1990s, reaching 260 Mt in 2014.

The growth in coal production during the 2000s coincided with the recommissioning of the Camden, Grootvlei and Komati power stations as part of Eskom's return-to-service programme, aimed at addressing shortfalls in electricity supply (Eskom, 2014: 18). Growth in coal export volumes was supported in the 2000s by further capacity expansions at RBCT, which reached a design capacity of 76 Mtpa in 2008 and 91 Mtpa in 2010 (RBCT, n.d.). However, the rail capacity and performance of Transnet Freight Rail consistently fell short of RBCT's export capacity during the period, which constrained export volume growth (Eberhard, 2011: 21).

4.1.2 GVA

Saleable coal production volumes are shown relative to GVA for the period 1980 to 2014 in **Figure 4.2**. During the 1980s, GVA was considerably more volatile than saleable production, experiencing sharp declines in 1981 and 1987. Since 1992, production tonnes and GVA have followed a similar trend, except for deviating trends in 2005 and 2014.

Table 4.1 Correlation coefficients for GVA and saleable production

	Period		
	1980 to 1992	1993 to 2014	Overall: 1980 to 2014
Correlation coefficient: GVA and saleable production	0,6883	0,9917	0, 9677

Data source: Quantec (2015)

The differing trends in the 1980s and converging trends since 1992 in GVA and saleable production are reflected in the correlation coefficients for the different time periods, as shown in **Table 4.1**. Given the different trends in production tonnes compared to GVA during the 1980s, productivity measures calculated using tonnes should be more stable (less volatile) for this period. Similarly, productivity calculated using production tonnes and GVA are expected to have converged since 1992.

4.2 Input measures

Two labour input measures, namely the number of employees and a derived hours worked measure, and one capital input measure, namely fixed capital stock, were examined.

4.2.1 Labour input measures

The number of coal mining employees between 1980 and 2014 is shown in **Figure 4.3**. The number of employees has shown wide variation during the period, steadily declining from its peak of 136 000 in 1981 to a low of 47 000 in 2002 and 2003. In 1992 and 1993, there was a sharp reduction in the number of employees employed in the coal mining sector, with an overall decline of almost 35 000 employees recorded in these two years alone. The number of employees has increased since 2003, reaching a level of around 86 000 in 2014.

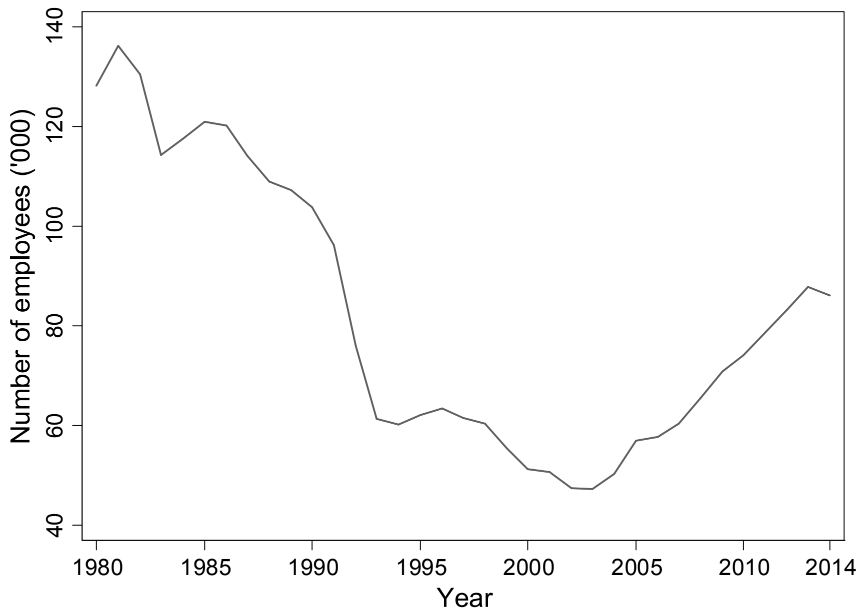
Peatfield (2003: 358) ascribes the reduction in employees during the 1990s to a growing trend of outsourcing of non-core activities by mining companies. The number of employees measure used in the analysis includes both mining company or “establishment” employees and outside contractors as per the DMR’s classification. As such, outsourcing during the 1990s would had to have shifted labour to a third category, not captured as labour by the DMR, to have had an impact on the number of employees measure.

The number of employees, average number of shifts worked and derived hours worked data for the period between 2005 and 2014 are shown in **Figure 4.4**[10]. The data on average shifts worked and number of employees follow each other very closely during this period, as illustrated by the correlation coefficient of 0,9988 for these two variables. Since the hours worked measure is a simple linear transformation of the shifts worked variable, it displays the same correlation with the number of employees.

It is expected that there will be some correlation between the shifts worked variable and the number of employees. However, shifts worked and the number of employees should represent different measurements, with shifts worked corresponding to clock card hours registered at the gate, while the number of employees corresponds to the payroll list on the last day of the month.

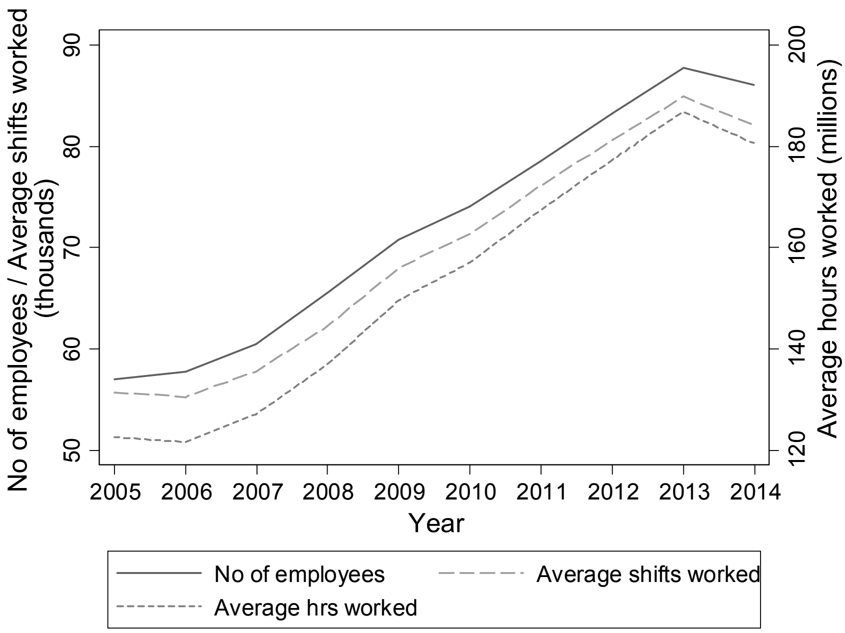
Further investigation is required to establish the reason for the high correlation between shifts worked and the number of employees. For the purposes of this research report, it is noted that the derived hours worked measure does not provide additional information compared to the number of employees measure.

[10] **Figure 4.4** only shows data from 2005 onwards, since this is the period for which shifts worked data was made available by the DMR.



Source: Quantec (2015)

Figure 4.3 Number of employees



Source: Quantec (2015); DMR (2015)

Figure 4.4 Number of employees, shifts worked and hours worked

The number of employees measure has the added benefit of being available for a much longer period. Therefore, the remainder of this research report uses only the number of employees as labour input measure.

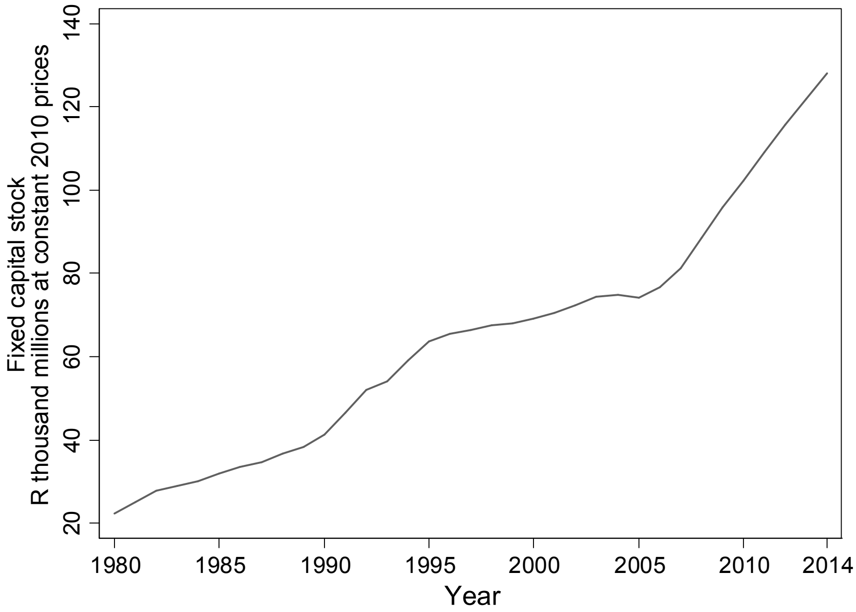
4.2.2 Capital input measure

The growth in the fixed capital stock for the coal mining industry between 1980 and 2014 is shown in **Figure 4.5**. Fixed capital stock grew at different rates during this period, as shown in **Table 4.2**. Between 1980 and 1990, fixed capital stock grew at a compound annual growth rate (CAGR) of 6,3 per cent. Growth accelerated to 9,0 per cent per annum between 1990 and 1995, before reverting to 1,6 per cent per annum for the next decade. Fixed capital stock again grew more rapidly between 2005 and 2014, reaching a CAGR of 6,2 per cent. Overall, fixed capital stock grew at 5,3 per cent per annum between 1980 and 2014.

The growth in fixed capital stock in the early 1990s could possibly be linked back to the outsourcing explanation and decline in the number of employees referred to in **Chapter 4.2.1**. An increase in outsourcing would be reflected in rising fixed capital stock if services previously rendered in-house were replaced by external contractors whose services are classified as capital services, rather than hired labour.

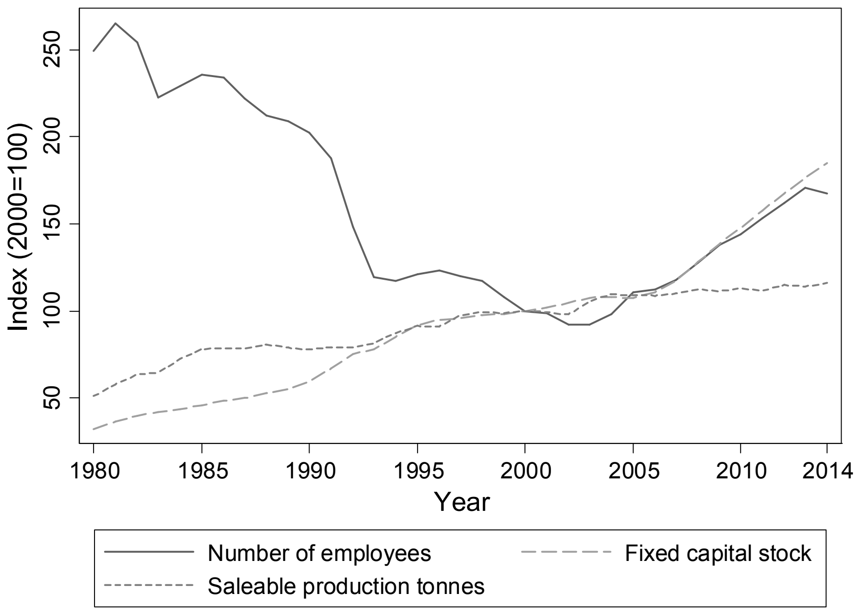
4.3 Comparison of output and input measures

Coal mining output is compared with capital and labour inputs for the period 1980 to 2014, using 2000 as base year, in **Figure 4.6**. Levels and compound annual growth rates of the input and output variables are summarised in **Table 4.2**.



Source: Quantec (2015)

Figure 4.5 Fixed capital stock



Source: Quantec (2015)

Figure 4.6 Employees, fixed capital stock and saleable production

Table 4.2 Saleable production, employees and fixed capital stock

	Year				
Levels	1980	1990	1995	2005	2014
Saleable production tonnes (millions)	115,0	175,0	205,6	245,0	261,0
Number of employees (000)	128,1	103,8	62,1	57,0	86,0
Fixed capital stock (R 000 million)	22,4	41,3	63,6	74,3	128,0
	Period				
Compound annual growth rates (percentage)	1980 to 1990	1990 to 1995	1995 to 2005	2005 to 2014	Overall: 1980 to 2014
Saleable production tonnes	4,3	3,3	1,8	0,7	2,4
Number of employees	-2,1	-9,8	-0,9	4,7	-1,2
Fixed capital stock	6,3	9,0	1,6	6,2	5,3

Data source: Quantec (2015)

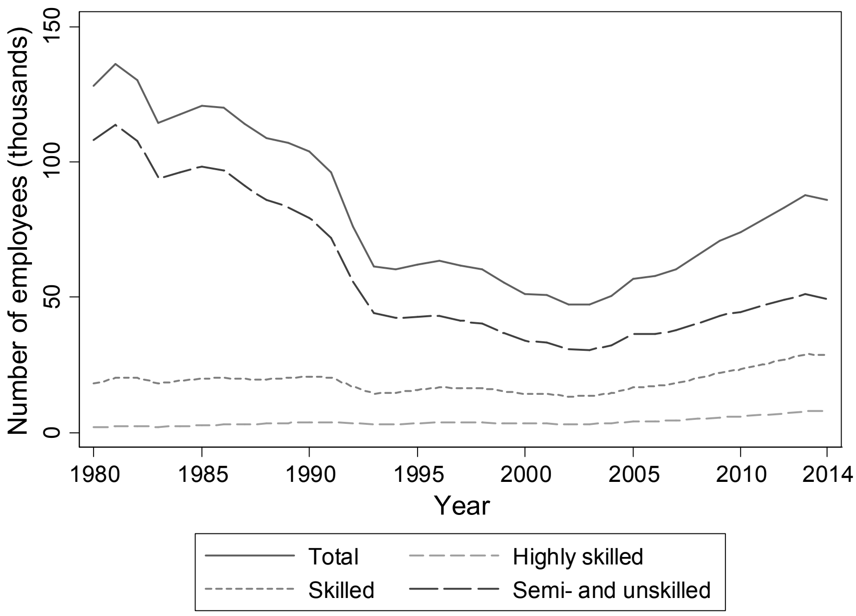
Prior to the early 2000s, growth in coal mining output corresponded with declining labour input and increasing capital input. This suggests that improvements in labour productivity were driven by capital deepening during the 1980s and 1990s.

Since 2003, both labour and capital inputs have been increasing together with coal mining output. The growth in output has consistently been at a lower rate than the growth in capital input (prior to 2003) and the growth in both labour and capital inputs (after 2003). This would suggest that both labour and capital productivity have been declining since 2003.

4.4 Skills composition of the labour force

Figure 4.7 and **Table 4.3** show the number of employees by skills level between 1980 and 2014. The overall reduction in the number of employees during this period was mainly driven by a reduction in the number of semi-skilled and unskilled employees, which declined from 108 000 in 1980 to 36 000 in 2005, before increasing again to 49 000 in 2014. The number of skilled employees was relatively constant during the period, showing a slight decline between 1980 and 2005. The number of highly skilled employees grew consistently throughout the period, albeit from a low level compared to other skills categories, almost quadrupling between 1980 and 2014.

As shown in **Table 4.3**, there was an overall shift in the skills composition of the coal mining workforce between 1980 and 2014, with highly skilled and skilled employees increasing from 16 per cent to 43 per cent during this period. In theory, shifts towards more skilled labour should lead to higher productivity, in line with the worker quality hypothesis outlined in **Chapter 2.2.4**. Based on these trends, it is expected that productivity would have increased between 1980 and 2014.



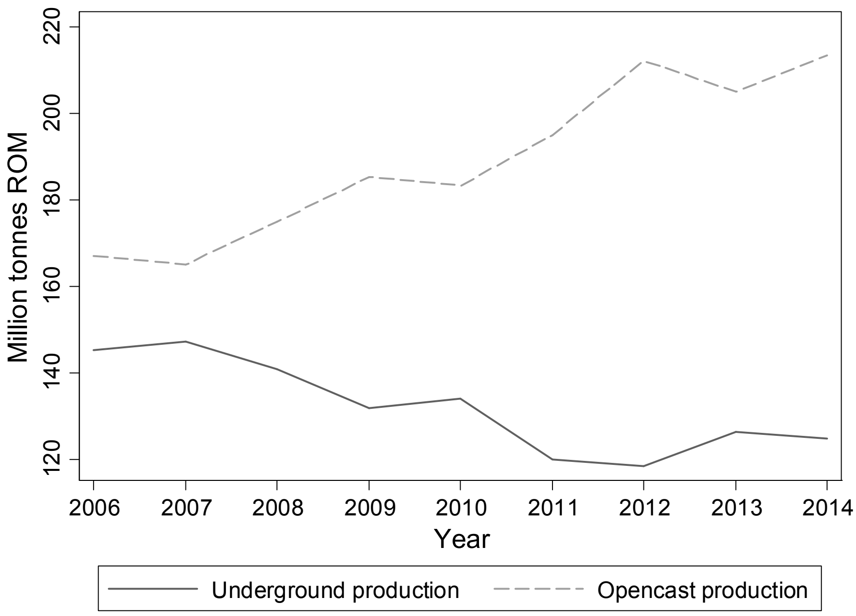
Source: Quantec (2015)

Figure 4.7 Number of employees by skills level

Table 4.3 Number of employees by skills level

Number of employees (000)	Year 1980	1990	1995	2005	2014
Highly skilled	2,0	3,8	3,4	4,0	7,9
Skilled	18,0	20,7	15,8	16,7	28,7
Semi- and unskilled	108,1	79,3	42,8	36,3	49,4
Total	128,1	103,8	62,1	57,0	86,0
Proportion of total (percentage)	**Year 1980**	**1990**	**1995**	**2005**	**2014**
Highly skilled	2	4	5	7	9
Skilled	14	20	25	29	33
Semi- and unskilled	84	76	69	64	57
Total	100	100	100	100	100

Data source: Quantec (2015)



Source: DMR (2015)

Figure 4.8 ROM production by mining method

4.5 Trends in mining methods

The DMR's production data was used to examine the changing composition of coal production by mining method between 2006 and 2014[11]. As shown in **Figure 4.8** and **Table 4.4**, coal production from underground mining methods has declined steadily from approximately 145 Mt in 2006 to 125 Mt in 2014. At the same time, opencast production has increased from approximately 165 Mt in 2006 to almost 215 Mt in 2014. In underground mining, longwall production has steadily declined from around 10 Mt in 2006 to only 1,7 Mt in 2014.

Table 4.4 shows that the proportion of production from underground mines has steadily declined from 47 per cent in 2006 to 37 per cent in 2014. Longwall mining declined from 3 per cent of total production in 2006 to 0,5 per cent of total production in 2014. Hardman (1996: 301) notes that

[11] The breakdown by mining method is limited to 2006 and later years, since this is the period for which the data was made available by the DMR.

labour productivity can be improved by changing mining methods, for example by moving from underground- to opencast mining or from bord and pillar- to longwall mining. As such, the shift towards opencast mining between 2006 and 2014 is expected to have resulted in an improvement in labour productivity. Conversely, the declining use of longwall mining would have resulted in declining labour productivity during this period, although the impact on overall productivity is expected to have been negligible given the small contribution of longwall mining to overall production.

Table 4.4 Coal production by mining method

	Year				
ROM production (Mt)	2006	2008	2010	2012	2014
Underground	145,4	140,9	134,2	118,7	124,9
Bord and pillar	118,4	116,7	118,4	110,9	123,2
Stooping	16,6	14,4	7,2	6,1	5,1
Longwall	10,4	9,8	8,7	1,6	1,7
Opencast	167,2	175,0	183,3	212,2	213,4
Total	312,6	315,9	317,5	330,8	338,2

	Year				
Proportion of total (percentage)	2006	2008	2010	2012	2014
Underground	46,5	44,6	42,3	35,9	36,9
Bord and pillar	37,9	37,0	37,3	33,5	36,4
Stooping	5,3	4,6	2,3	1,9	1,5
Longwall	3,3	3,1	2,7	0,5	0,5
Opencast	53,5	55,4	57,7	64,1	63,1
Total	100	100	100	100	100

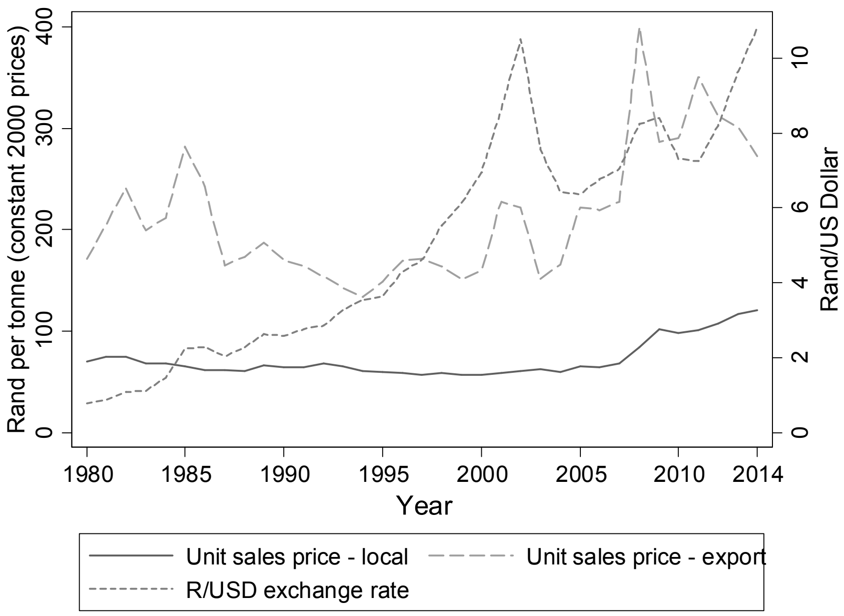
Data source: DMR (2015)

4.6 Trends in coal sales prices

Trends in real local and export sales prices and the Rand/US Dollar exchange rate are shown in **Figure 4.9**. Domestic coal prices have been very stable in real terms for most of the period. Since 2008, domestic coal prices have increased above inflation, with significant above-inflationary increases recorded in 2008 and 2009 in particular.

The recent increase in domestic coal prices reflects greater reliance by Eskom on more costly short-term contracts. Eberhard (2011: 16) attributes the increased reliance on short-term contracts to three factors, namely: power stations being run at capacity factors in excess of existing long-term coal supply agreements; increased requirements to procure from companies which meet black economic empowerment (BEE) requirements; and shortfalls in contracted coal supplies to Eskom's Majuba and Tutuka power stations.

Export coal prices have been far more volatile than domestic prices in real terms, partly reflecting volatility in the SA currency. Export coal prices showed a general declining trend in real terms until 2003. This excludes an increase in 2001 and 2002, which was mostly related to the sharp depreciation of the Rand in these two years. Since 2003, export coal prices have shown a general increasing trend, reflecting the depreciation of the rand as well as strong global demand for export coal. Historically, the Rand/US Dollar exchange rate and export coal prices have tended to move in opposite directions, with the weakening of the Rand coinciding with lower coal prices and vice versa.



Source: Quantec (2015); http://www.federalreserve.gov/

Figure 4.9 Local and export sales prices and R/USD exchange rate

Table 4.5 Predicted direction of productivity growth

	Period		
	1980s	1990s	2000s
Output relative to input (labour and capital)	Increasing	Increasing	Decreasing
Skills composition of the labour force	Increasing	Increasing	Increasing
Mining methods	No data	No data	Increasing
Coal sales prices	Stable / Increasing	Stable / Increasing	Decreasing
Overall	Increasing	Increasing	Uncertain

As noted in **Chapter 2.2.9**, productivity tends to move inversely with cyclical trends in real commodity prices. Therefore, based on the trends in SA coal prices highlighted above, the expectation is that productivity would have been stable or increasing during the 1980s and 1990s and would have declined during the 2000s.

4.7 Summary and predictions from descriptive analysis

Table 4.5 summarises the findings from the descriptive analysis in terms of the predicted direction of productivity growth between 1980 and 2014.

During the 1980s and 1990s, the evolution of output growth relative to the growth in labour and capital inputs, the changing skills composition of the workforce and trends in coal sales prices all suggest that productivity would have been increasing during this period. The establishment of new mines during this period to supply coal to Eskom's new fleet of power stations and export demand also would have allowed for the introduction of newer, more productive mining technologies.

The direction and magnitude of changes in labour inputs and capital inputs during the early 1990s may have been driven by growing outsourcing and the substitution of capital for labour during this period. This would have been the case if services previously rendered in-house were replaced by external contractors classified as capital services.

During the 2000s, the trends in output relative to inputs and coal sales prices were reversed, pointing to a reduction in productivity growth. The changing skills composition of the labour force and changing mining methods, however, are expected to have had a positive impact on productivity growth. As such, the overall impact on the direction of productivity growth during the 2000s is not immediately evident from the descriptive analysis.

5 TRENDS IN SA COAL MINING PRODUCTIVITY

Chapter 5 presents trends in SA coal mining productivity, based on the calculated labour productivity and TFP measures. It also presents results from the decomposition of labour productivity growth into underlying TFP growth and capital-labour ratio growth components.

5.1 Labour productivity

Labour productivity is examined from the perspective of levels and growth rates using both the number of employees and GVA as output measures. Labour productivity in the coal mining sector is also compared to labour productivity for the SA economy as a whole.

5.1.1 Labour productivity levels

Figure 5.1 shows saleable tonnes per employee and GVA per employee for the coal mining industry between 1980 and 2014. The two labour productivity measures track each other very closely, indicating that labour productivity increased between 1980 and 2003 and declined between 2003 and 2014.

Saleable tonnes per employee increased from around 1 000 tonnes per employee per year in 1980 to a peak of 5 000 tonnes per employee in 2003, before falling back to around 3 000 tonnes per employee in 2014. Similarly, GVA per employee increased from around R150 000 per employee in 1980 (in constant 2010 prices) to almost R1 million per employee in 2003, before reverting to around R600 000 per employee in 2014.

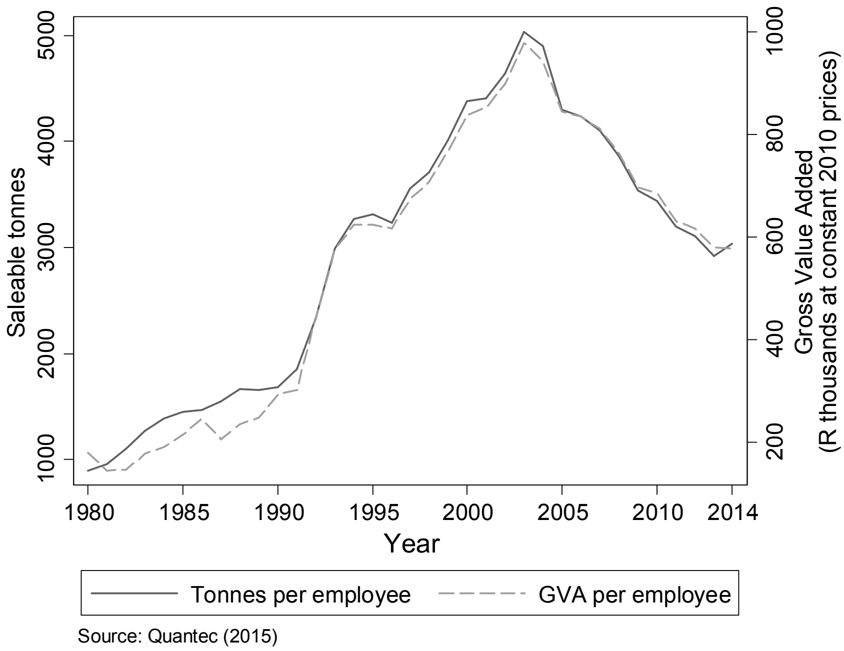


Figure 5.1 Coal mining labour productivity levels

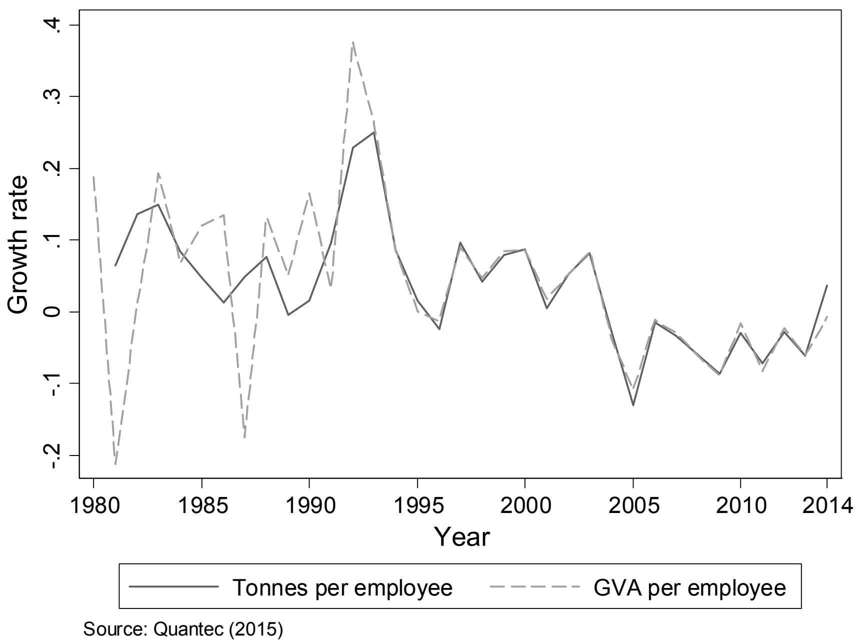


Figure 5.2 Coal mining labour productivity growth

Referring back to **Figure 4.3**, which shows the number of employees between 1980 and 2014, trends in labour productivity appear to have been driven largely by changes in the number of employees, with the peak in labour productivity in 2003 corresponding to the low point in the number employees in the coal mining sector.

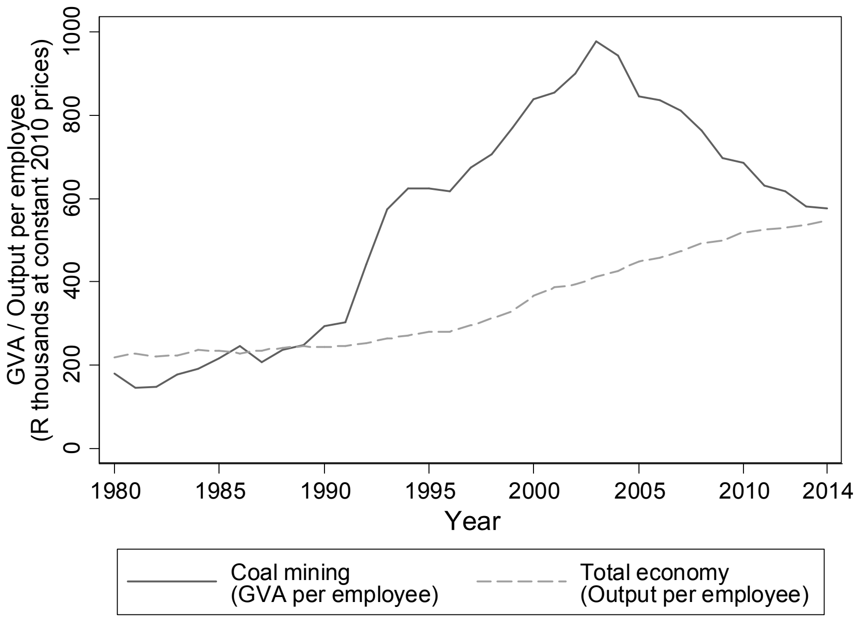
5.1.2 Labour productivity growth

Figure 5.2 shows growth in tonnes per employee and GVA per employee. Both measures of labour productivity growth are relatively volatile, with an increase in the growth rate typically followed by a decrease in the following year. As noted above, labour productivity growth was positive for the most part between 1980 and 2003, with negative labour productivity growth recorded from 2004 onwards.

Growth in GVA per employee was significantly more volatile than growth in tonnes per employee until 1992. Since 1993, however, the two measures of labour productivity growth have been very similar, as evidenced by the correlation coefficient of 0,9873 for the years 1993 to 2014 for these two variables.

5.1.3 Coal mining labour productivity relative to SA economy

Figure 5.3 and **Table 5.1** compare labour productivity in the coal mining industry to labour productivity for the total SA economy, based on value added and output. During the 1980s, labour productivity in the coal mining industry was broadly in line with the overall SA economy.



Source: Quantec (2015)

Figure 5.3 Coal mining and total economy labour productivity

Table 5.1 GVA and output per employee

R thousands at constant 2010 prices	Year				
	1980	1990	1995	2005	2014
Coal mining (GVA per employee)	180,8	293,3	625,0	844,9	576,7
Total economy (output per employee)	218,4	244,7	279,5	449,2	546,2
	Period				
Compound annual growth rates (percentage)	1980 to 1990	1990 to 1995	1995 to 2005	2005 to 2014	Overall: 1980 to 2014
Coal mining (GVA per employee)	5,0	16,3	3,1	-4,2	3,5
Total economy (output per employee)	1,1	2,7	4,9	2,2	2,7

Data source: Quantec (2015)

From the beginning of the 1990s until 2003, coal mining productivity increased at a much faster rate than productivity in the overall economy so that by 2003 labour productivity in the coal mining industry was almost two and a half times that of the total economy. However, with the decline in productivity since 2003, labour productivity in the coal mining sector was again at roughly the same level as that of the total economy in 2014.

Overall, labour productivity in the coal mining sector grew at a compound annual growth rate of 3,5 per cent between 1980 and 2014, compared to growth in the total economy of 2,7 per cent. Coal mining labour productivity growth was particularly high during the early 1990s, with a growth rate of 16,3 per cent recorded between 1990 and 1995, compared to only 2,7 per cent in the total economy.

5.2 Capital intensity

Figure 5.4 shows capital stock per employee for the coal mining industry between 1980 and 2014. There is evidence of capital deepening, or a rise in capital intensity, between 1980 and 2003. There was a sharp increase in capital stock per employee in 1991, 1992 and 1993, in particular, with a compound annual growth rate of 20,8 per cent recorded between 1990 and 1995. As noted above for labour productivity, this is mostly due to the large decrease in the number of employees recorded in these years.

Capital stock per employee shows a similar trend to that shown by labour productivity between 1980 and 2005, which is aligned with the concept of capital deepening as a driver of labour productivity. Since 2005, however, there has been a divergence between labour productivity and capital stock per worker, with continued capital deepening coinciding with a decline in labour productivity between 2005 and 2014.

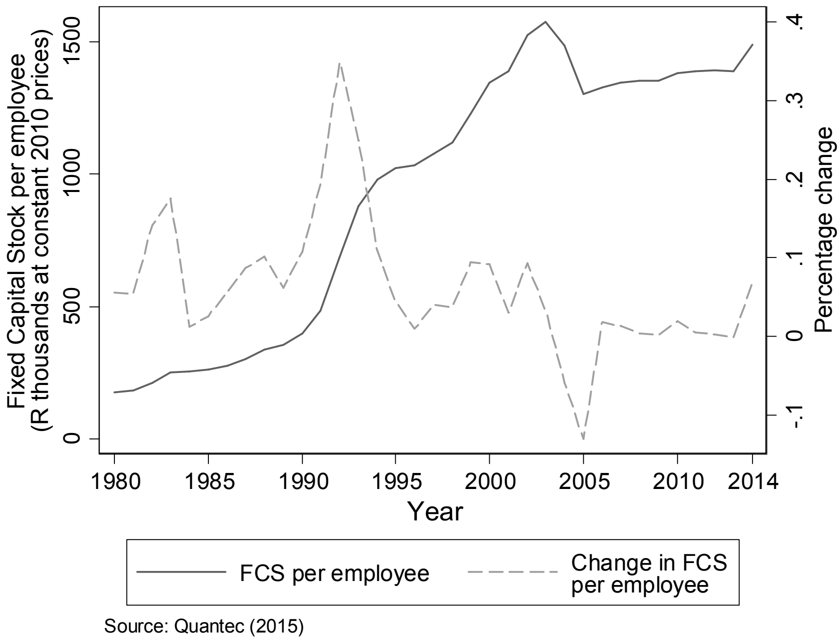


Figure 5.4 Capital stock per employee

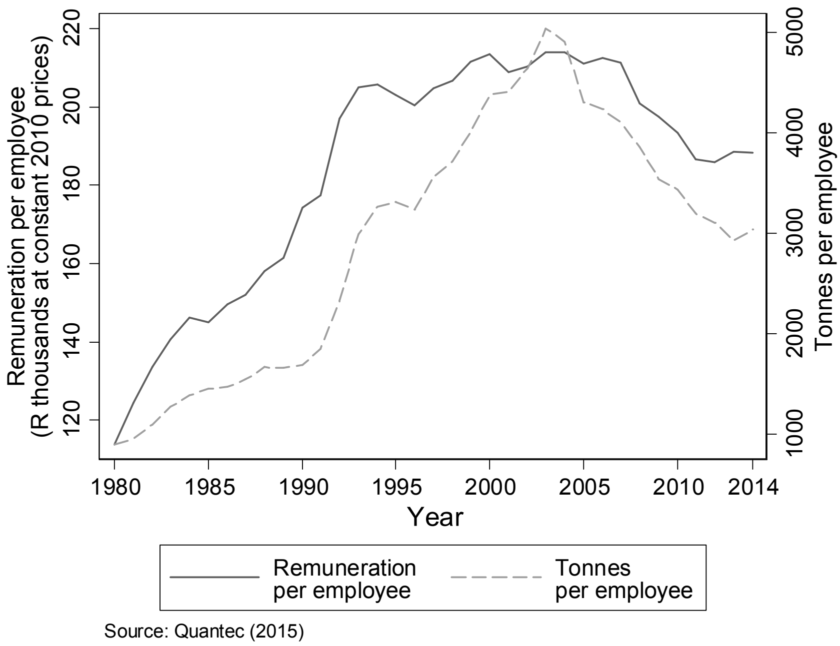


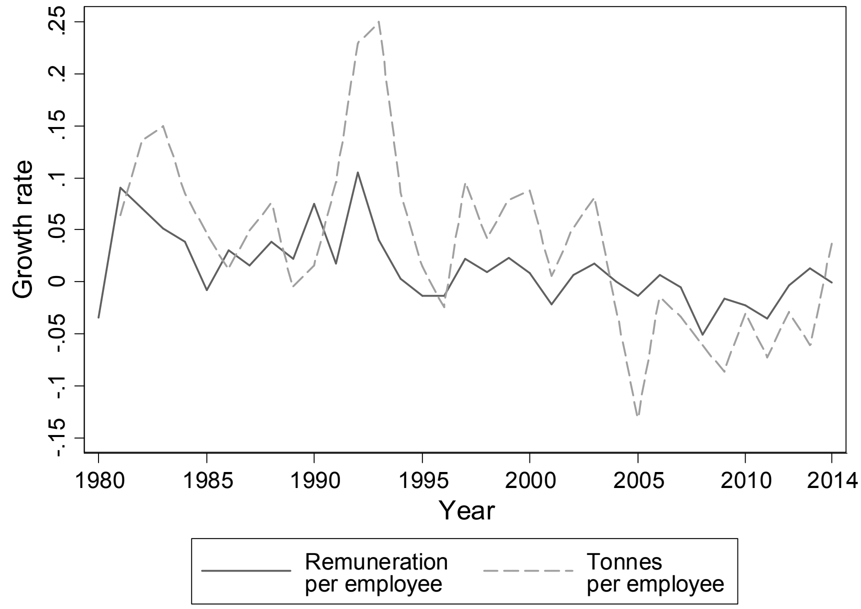
Figure 5.5 Labour productivity and remuneration per employee

5.3 Labour remuneration

Figure 5.5 shows labour remuneration compared to labour productivity as measured by tonnes per employee between 1980 and 2014. Remuneration increased consistently in real terms from R113 761 per employee in 1980 to R205 051 per employee in 1993. Remuneration continued to increase only marginally after 1993, reaching a peak of around R210 000 per employee by the mid-2000s. Since 2007, labour remuneration has declined in real terms. By 2014, remuneration had receded to R188 326 per employee, which was similar in real terms to labour remuneration levels observed in the early 1990s.

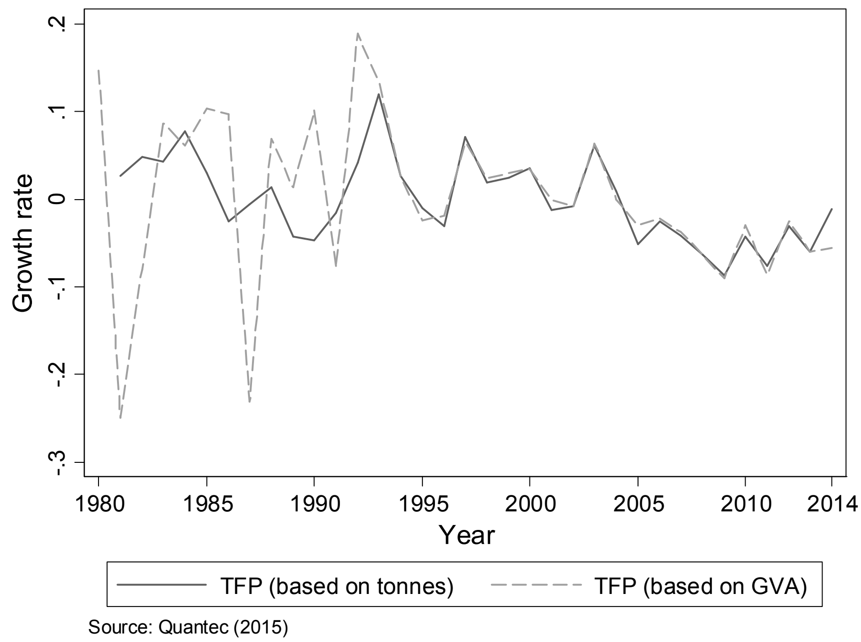
As shown in **Figure 5.6** and **Table 5.2**, labour productivity growth outpaced the growth in labour remuneration between 1980 and 2014. Remuneration grew by only 1,5 per cent per annum in the overall period, compared to growth in labour productivity of 3,6 per cent per annum. During the same period, capital intensity grew at a faster rate than both labour productivity and labour remuneration.

The overall period can be divided into two distinct sub-periods. Until 2003, both labour productivity growth and labour remuneration growth were positive and labour productivity growth tended to exceed the growth in labour remuneration. The period since 2003, however, has been characterised by negative growth in both labour productivity and remuneration, with labour remuneration declining at a slower rate than the decline in labour productivity.



Source: Quantec (2015)

Figure 5.6 Labour productivity and remuneration (growth rates)



Source: Quantec (2015)

Figure 5.7 TFP growth based on GVA and saleable tonnes

Table 5.2 Labour productivity, capital intensity and remuneration

	Year				
Levels	1980	1990	1995	2005	2014
Labour productivity (Tonnes per employee)	898,0	1 685,7	3 313,3	4 300,2	3 033,6
Capital intensity (FCS per employee)*	174,9	397,8	1 024,3	1 303,9	1 488,0
Remuneration per employee*	113,8	174,2	203,0	210,9	188,3
	Period				
Compound annual growth rates (percentage)	1980 to 1990	1990 to 1995	1995 to 2005	2005 to 2014	Overall: 1980 to 2014
Labour productivity (Tonnes per employee)	6,5	14,5	2,6	-3,8	3,6
Capital intensity (FCS per employee)	8,6	20,8	2,4	1,5	6,5
Remuneration per employee	4,4	3,1	0,4	-1,3	1,5

Data source: Quantec (2015)
*Note: Fixed capital stock and remuneration are measured in Rand thousands at constant 2010 prices.

5.4 TFP

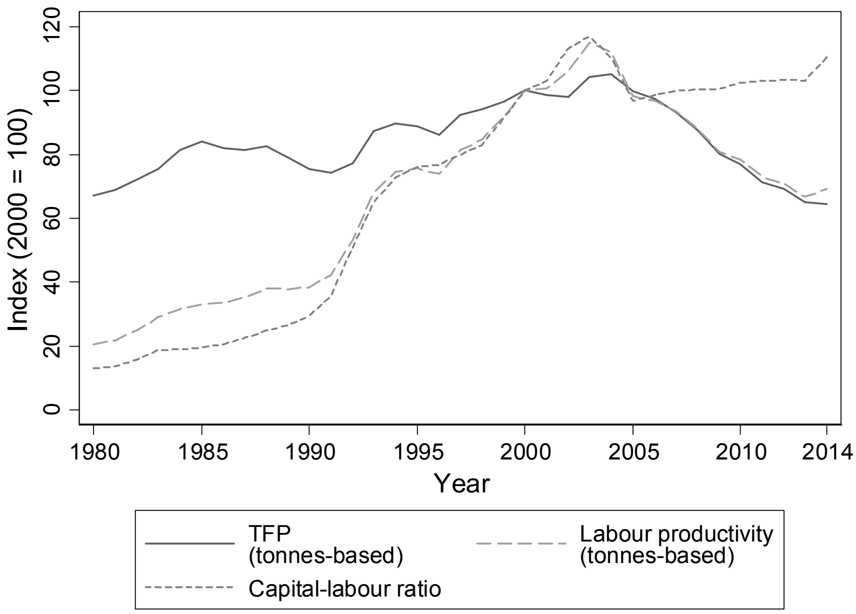
Figure 5.7 shows TFP growth calculated using GVA and saleable tonnes as output measures. The trends in TFP growth are very similar to those observed for labour productivity growth, with significant up-and-down movements between years, greater volatility in GVA-based TFP growth compared to tonnes-based TFP growth until 1993 and coinciding TFP growth rates in both measures from 1993 until 2014. Given the similarity in the tonnes-based measures after 1993 for both labour productivity growth (as described in **Chapter 5.1.2**) and TFP growth, the remainder of this chapter will focus on tonnes-based productivity measures.

TFP growth based on saleable tonnes peaked on four occasions between 1980 and 2014, with peaks occurring in 1984 at 7,7 per cent, in 1993 at 12 per cent, in 1997 at 7,1 per cent and in 2003 at 6,1 per cent. TFP growth also turned negative on a number of occasions, notably from 1986 until 1991, in 1995, 1996, 2001 and 2002 and from 2005 until 2015. Since TFP growth is essentially a residual measure, these instances of negative growth can be interpreted as periods where growth in capital intensity did not translate into proportionate growth in labour productivity.

5.5 Decomposition of labour productivity growth

Figure 5.8 shows labour productivity relative to TFP and capital intensity using 2000 as base year. While labour productivity and capital intensity tended to move together and showed strong gains until around 2005, TFP grew by much less over the same period. This indicates that much of the observed gains in labour productivity between 1980 and 2005 were driven by capital deepening. Since 2005, labour productivity and TFP have tended to move together with a declining trend. Capital intensity initially declined in 2003 and 2004, but reverted to a moderately positive growth rate from 2005 onwards. Notably, the decline in TFP since 2005 has reversed most of the gains made during the period, with TFP levels in 2014 roughly the same as those recorded in 1980.

Table 5.3 shows the decomposition of labour productivity growth into TFP growth and the effect of changes in the weighted capital-labour ratio. In the 1980s, the moderate growth in labour productivity was mostly due to capital deepening, with less than 20 per cent attributable to TFP growth. The contribution of TFP growth to labour productivity growth increased to around 25 per cent between 1990 and 1995. The exceptional growth in labour productivity in this period was still primarily driven by an increase in the capital-labour ratio.



Source: Quantec (2015)

Figure 5.8 Labour productivity, TFP and capital intensity index

Between 1995 and 2005, the split between TFP growth and capital deepening became more equal at 45 per cent and 55 per cent, with labour productivity growth slowing down to only 2,6 per cent per annum during this period. From 2005 to 2014, labour productivity declined despite continued growth in the capital-labour ratio. As a result, TFP growth was negative in this period.

Overall, TFP growth for the period 1980 to 2014 made a negative contribution to labour productivity growth, with labour productivity growth being lowered by 0,1 per cent from 3,7 per cent to 3,6 per cent in absolute terms. However, as noted above, the negative contribution was mostly the result of a delinking between changes in the capital-labour ratio and labour productivity from 2005 onwards.

Table 5.3 Decomposition of labour productivity growth

	Period				
Compound annual growth rates (percentage)	1980 to 1990	1990 to 1995	1995 to 2005	2005 to 2014	Overall: 1980 to 2014
Labour productivity (Tonnes per employee)	6,5	14,5	2,6	-3,8	3,6
Total factor productivity (tonnes-based)	1,2	3,3	1,2	-4,8	-0,1
Capital intensity (FCS per employee)	8,6	20,8	2,4	1,5	6,5

	Period				
Absolute contribution to labour productivity growth (average annual growth rate)	1980 to 1990	1990 to 1995	1995 to 2005	2005 to 2014	Overall: 1980 to 2014
Labour productivity (Tonnes per employee)	6,3	13,5	2,6	-3,9	3,6
Total factor productivity (tonnes-based)	1,2	3,3	1,2	-4,9	-0,1
Weighted capital-labour ratio	5,1	10,3	1,4	1,0	3,7

	Period				
Relative contribution to labour productivity growth (percentage contribution)	1980 to 1990	1990 to 1995	1995 to 2005	2005 to 2014	Overall: 1980 to 2014
Labour productivity (Tonnes per employee)	100,0	100,0	100,0	100,0	100,0
Total factor productivity (tonnes-based)	18,6	24,1	45,2	125,6	-3,3
Weighted capital-labour ratio	81,4	75,9	54,8	-25,6	103,3

Data source: Quantec (2015)

5.6 Summary: Productivity trends 1980 to 2014

The analysis of labour productivity and TFP suggests that the overall period between 1980 and 2014 can be divided into two distinct sub-periods:

- **1980 to 2003: Positive labour productivity growth and TFP growth.** Labour productivity growth was primarily driven by capital deepening in this period, with increasing capital intensity explaining roughly 80 per cent of the growth in labour productivity in the 1980s, 75 per cent of the growth between 1990 and 1995 and 50 per cent of the growth between 1995 and 2005. Labour remuneration growth was also positive in this period, but grew at a slower rate than labour productivity. Labour productivity growth was particularly strong in the early 1990s, growing at 14,5 per cent per annum between 1990 and 1995, while the capital-labour ratio grew even more rapidly, gaining 20,8 per cent per annum in the same period. Both labour productivity and the capital-labour ratio reflect the large decrease in the number of coal mining employees during the early 1990s.
- **2004 to 2014: Negative labour productivity growth and TFP growth.** Labour productivity growth was negative from 2004 onwards, despite continued capital deepening between 2005 and 2014. As a result of labour productivity declining at the same time that capital intensity was growing, TFP growth was also negative in this period. Labour remuneration also declined in this period, although at a slower rate than labour productivity.

The results from the productivity analysis provide confirmation of the predictions presented in **Chapter 4**, with positive growth in productivity until the 2000s and declining productivity since 2003. Given that the recent decline in productivity has not been driven by changes in the capital-labour ratio, other explanations need to be considered.

Referring back to **Chapter 4.7**, changes in skills composition (towards more skilled labour) and mining methods (towards opencast mining) would have supported an increase in productivity and, as such, do not explain the decline in productivity since the mid-2000s. However, the significant growth in coal sales prices is consistent with deteriorating productivity in the 2000s.

5.7 Other explanations for deteriorating productivity

Declining productivity in the 2000s may have been caused by a number of factors at individual mine level. As part of a possible long-term trend, the negative impacts of resource depletion may have outweighed the positive impacts of innovation and technological change. In the shorter term, the establishment of new collieries may have resulted in a temporary decline in productivity while production was being built up to full capacity and debottlenecking was taking place.

Unfortunately, in the absence of publicly available microdata at individual mine level, it is difficult to investigate the relative contribution of these factors on productivity. In the case of the SA coal mining industry, company annual reports generally only include information on a highly aggregated basis and very rarely include information on productivity measures or even the number of employees.

While the DMR collects detailed data on individual mine level, for confidentiality reasons it can only be made available on an aggregated level. This is in contrast, for instance, to the Part 50 data collected by the US MSHA, which is a similar dataset and is made available to the general public including information on an individual mine basis, thereby allowing for the application of panel data techniques which take into account geographical, geological, and technological heterogeneity[12]. One possible solution may be to provide access to the full disaggregated dataset to accredited researchers through a secure data repository. Secure data repositories have been established in many developed countries[13] and SA has a secure data facility at the DataFirst Secure Research Data Centre at the University of Cape Town[14].

A number of additional factors may have further contributed to deteriorating productivity in the 2000s. More stringent enforcement of safety regulations may have resulted in a greater incidence of stoppages for safety reasons. There is anecdotal evidence that mine safety stoppages in terms of Section 54 of the Mine Health and Safety Act No. 29 of 1996 have become more frequent and widely applied, with a detrimental impact on production (Seccombe, 2015). This was particularly the case in the platinum industry, but may also have had a significant impact in coal mining. Moreover, increased focus on improving safety performance may have triggered changes in mining companies' work practices and safety standards, resulting for example in more time spent on non-productive activities such as installing roof support.

Another potential explanation for falling productivity is labour unrest and strike action in the 2000s, which may have resulted in an increase in lost workdays. **Figure 5.9** shows data on the severity of strikes for the SA mining and quarrying sector since 1998, measured as the number of workdays lost per

---

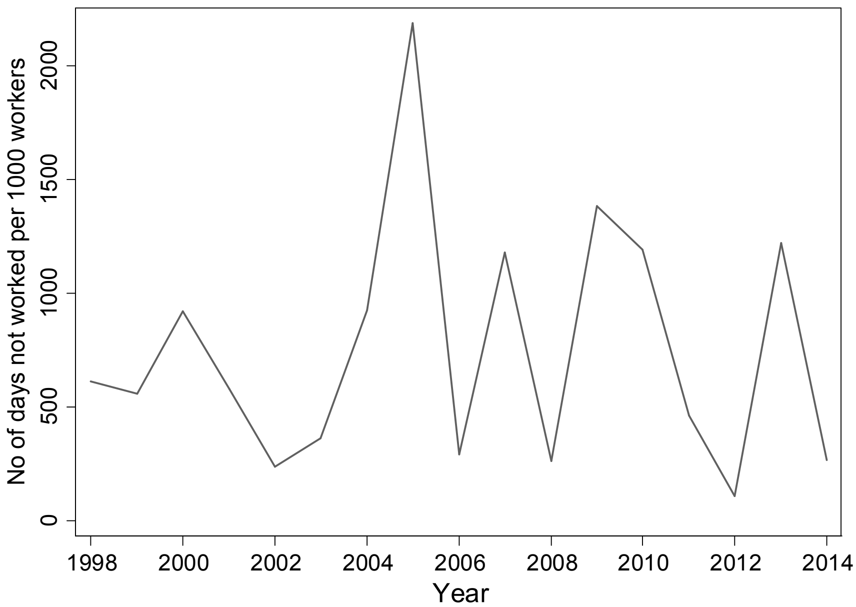
[12] The US MSHA information is collected under Title 30 Code of Federal Regulations, Part 50 and is more commonly known as "Part 50 data".

[13] Refer for example to the website of the UK Data Archive Secure Data Service: https://www.ukdataservice.ac.uk/get-data/how-to-access/accesssecurelab

[14] The centre provides access for accredited researchers to detailed government data not otherwise available to researchers. Responsible, bona fide researchers based at universities or other research institutions are eligible for accreditation from the centre for valid data usage purposes (DataFirst 2012; 2013).

1 000 workers. Looking at the peaks in 2005, 2007, 2009 and 2013, it is difficult to discern a clearly increasing trend, although strike severity appears to have been higher after 2003 than before. Unfortunately, data on the number of workdays lost is not reported separately for the coal mining industry and the labour relations framework climate differs between mineral commodities. As such, labour instability in the platinum or gold mining industries would not necessarily have carried over to the coal mining industry and vice versa.

The next chapter compares recent productivity trends in the SA coal mining industry to evidence from the US and Australian coal mining sectors to determine whether similar trends can be observed globally and to seek potential explanations which may be common to all three jurisdictions.



Source: Quantec (2015)

Figure 5.9 Workdays lost to strike and lockouts (mining and quarrying)

6 INTERNATIONAL COMPARISON

Chapter 6 compares SA coal mining productivity with trends in Australia and the US. The comparison is done on the basis of labour productivity calculated as tonnes per employee. Tonnes per employee is a convenient measure for international comparisons, since it does not require adjustments for cross-country differences in relative price levels and exchange rates, avoids measurement problems associated with TFP and is easy to interpret (Van Ark, 1996: 37).

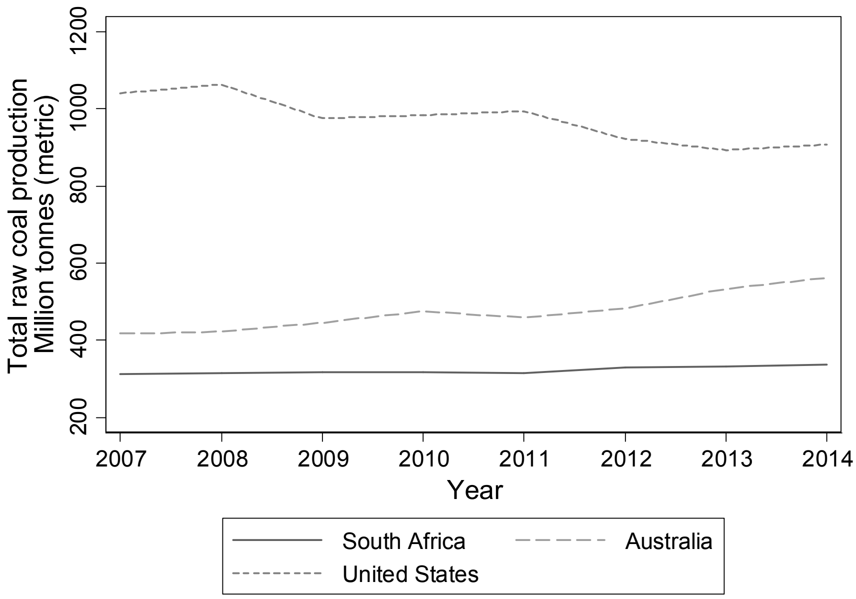
The number of employees was used as labour input measure, following on from **Chapter 4.2.1**, which found that the hours worked measure calculated from the DMR's shifts worked data was too closely correlated with the employment data to be useful. This is far from ideal, given that working hours may differ significantly between countries due to different legal and regulatory frameworks and employment practices (Van Ark, 1996: 25). For example, as noted in **Chapter 2.5.3**, SA has a shorter work week and more public holidays than its peers, implying that the average number of hours worked per employee is likely to be much lower in SA than in Australia or the US. As such, if labour productivity had instead been measured as tonnes per hour worked instead of tonnes per employee, SA would have appeared relatively more productive.

The international comparison was restricted to the period between 2007 and 2014, since data was available for all three jurisdictions only from 2007 onwards. **Table 6.1** provides an overview of the data and labour productivity measures for the three countries.

Table 6.1 International production, labour input and labour productivity

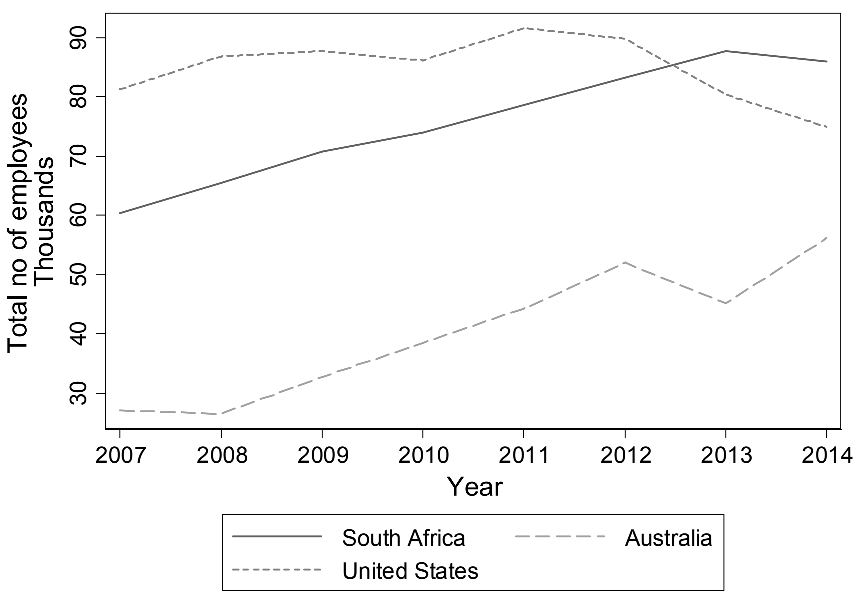
Raw production (million metric tonnes)	Year 2007	Year 2010	Year 2014	CAGR: 2007 to 2014
South Africa	312	318	338	1%
Australia	417	476	562	4%
United States	1 040	984	907	-2%
Number of employees (thousands)	**2007**	**2010**	**2014**	**CAGR: 2007 to 2014**
South Africa	60,4	74,0	86,0	5%
Australia	27,0	38,4	56,1	11%
United States	81,3	86,2	74,9	-1%
Labour productivity (tonnes per employee)	**2007**	**2010**	**2014**	**CAGR: 2007 to 2014**
South Africa	5 167	4 290	3 932	-4%
Australia	15 434	12 382	10 011	-6%
United States	12 798	11 413	12 108	-1%
Labour productivity (Australia 2007 = 100)	**2007**	**2010**	**2014**	**CAGR: 2007 to 2014**
South Africa	33	28	25	-4%
Australia	100	80	65	-6%
United States	83	74	78	-1%

Data source: DMR (2015); US EIA (2016); Australian Department of Industry, Innovation and Science (2016b)



Source: DMR (2015); US EIA (2016); Australian Department of Industry, Innovation and Science (2016)

Figure 6.1 Coal production: SA, Australia and US



Source: DMR (2015); US EIA (2016); Australian Department of Industry, Innovation and Science (2016)

Figure 6.2 Number of employees: SA, Australia and US

6.1 Production trends

Figure 6.1 compares total raw coal production for SA, Australia and the US. SA coal production grew by a modest 1 per cent per annum between 2007 and 2014, from 312 Mt in 2007 to 338 Mt in 2014.

US coal production declined by 2 per cent per annum from 1 040 Mt in 2007 to 907 Mt in 2014. US coal producers faced a challenging domestic environment during this period, including lower coal prices, strong competition from shale gas and growing societal pressure to move towards cleaner sources of energy. In response, US coal producers have switched away from domestic supply and increased exports to European markets, which has in turn worsened excess global supply and weakened global coal prices (Deloitte, 2013: 13). Since 2012, US coal producers have struggled to compete in global markets in the face of weakening demand due to their relatively higher production cost and a strong dollar (McKinsey Metals & Mining Practice, 2015: 7).

Australia recorded a significant increase of 4 per cent per annum over the period, growing from 417 Mt in 2007 to 562 Mt in 2014. The growth in Australian coal production reflects the expansion of existing mine capacity and development of new mines, mainly for export to China (BREE, 2014: 12; 16). In recent years, a number of Australian coal mines have reduced output or suspended operations to minimise losses in response to much lower coal prices. However, this has been offset by new capacity coming into operation, reflecting the investment lag[15] effect (Australian Department of Industry, Innovation and Science, 2016a: 15).

[15] Refer to **Chapter 2.5.5** for a discussion of the mining investment lag effect.

6.2 Labour trends

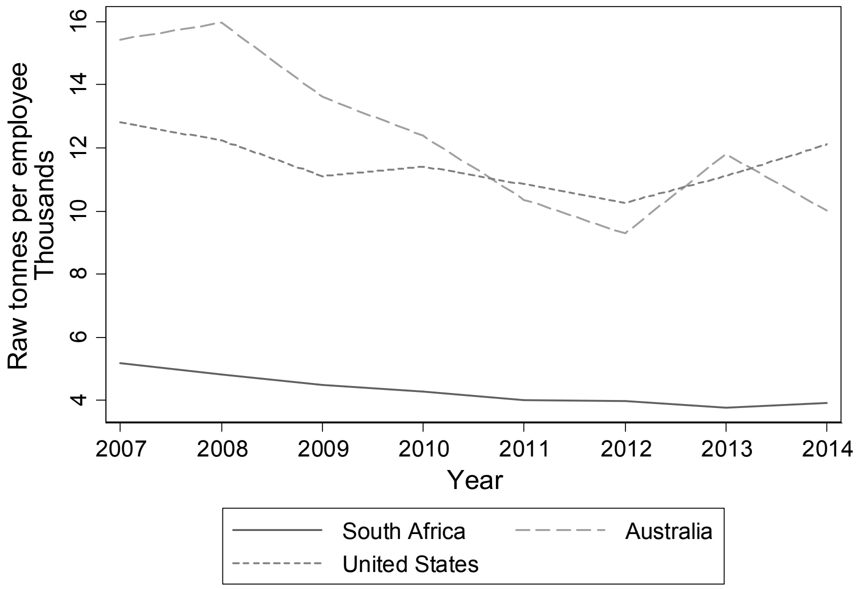
Figure 6.2 compares the evolution of the number of employees in SA, Australia and the US between 2007 and 2014. The number of employees in the SA coal mining sector grew at a rate of 5 per cent per annum during the period, from 60 400 employees in 2007 to 86 000 employees in 2014.

The US coal mining labour force grew from 81 300 employees in 2007 to 91 600 employees in 2011. Since 2012, however, the US coal mining sector has shed jobs and employment declined to 74 900 employees in 2014. As a result, the US showed an overall decline of 1 per cent per annum between 2007 and 2014 and in 2013 SA overtook the US with the largest coal mining labour force among the three countries.

The Australian labour force more than doubled during the period, growing at a rate of 11 per cent per annum from 27 000 employees in 2007 to 56 100 employees in 2014.

6.3 Labour productivity trends

Figure 6.3 shows the combined effect of trends in output and the number of employees as measured by labour productivity. SA labour productivity remained the lowest among the three countries between 2007 and 2014, varying between 30 and 40 per cent of the levels of its peers. At the same time, SA labour productivity declined at a rate of 4 per cent per annum from 5 167 tonnes per employee in 2007 to 3 932 tonnes per employee in 2014. US labour productivity declined until 2012, but recovered in 2013 and 2014, reflecting the reduction in employment.



Source: DMR (2015); US EIA (2016); Australian Department of Industry, Innovation and Science (2016)

Figure 6.3 Labour productivity: SA, Australia and US

Overall, US labour productivity declined by 1 per cent per annum from 12 798 tonnes per employee in 2007 to 12 108 tonnes per employee in 2014.

In 2007, Australian labour productivity was the highest in the comparison group at 15 434 tonnes per employee. Australian labour productivity declined sharply between 2007 and 2012, reaching a low point of 9 292 tonnes per employee in 2012. Labour productivity recovered slightly in 2013 and 2014, resulting in an overall decline of 6 per cent per annum between 2007 and 2014. Australian labour productivity has remained at levels close to that of the US of around 12 000 tonnes per employee since 2011.

The lower portion of **Table 6.1** summarises the relative performance of the three countries, using Australian labour productivity in 2007 as the baseline. SA labour productivity declined from approximately one third of the baseline in 2007 to a quarter of the baseline in 2007. US labour productivity was more consistent, declining from 83 per cent of the baseline in 2007 to 78 per cent of the baseline in 2014. Australian labour productivity showed the greatest decline and by 2014 had fallen to only 65 per cent of its initial level in 2007.

6.4 Explanations of international trends in the 2000s

Chapter 6.4 reviews explanations for recent trends in global coal mining productivity from scholarly literature, where available, and also assesses explanations from non-scholarly sources including popular, trade and professional literature. Since specific references to coal mining productivity were not always readily available, this chapter also examines explanations of the general slowdown in mining productivity across commodities.

6.4.1 US coal mining productivity in the 2000s

The most recent scholarly studies of coal mining productivity in the US date from the early 2000s and only cover the period up to 1995 (refer **Chapter 2.3**). As such, they do not shed light on the slowdown in US labour productivity since the 2000s.

Turning instead to popular literature, an article by Kuykendall and Qureshi (2014) provides some possible explanations for the US productivity slowdown. The authors highlight the interplay between technological advances and resource depletion, but importantly they also distinguish between the different experiences in the Central Appalachian Basin, the Powder River Basin and the Illinois Basin.

The Central Appalachian Basin has seen the steepest decline in productivity, with underground mines recording a decline of 54 per cent from the peak of 4,15 tons[16] per employee hour in 1999 to 1,92 tons per employee hour in 2013. Surface mines recorded a similar decline of 49 per cent from 6,11 tons per employee hour at the peak in 2000 to 3,13 tons per employee hour in 2013 (Kuykendall and Qureshi, 2014: 1). Central Appalachia has been mined more intensely and for a longer period than other US coal basins. With the depletion over time of thicker and shallower coal seams, Central Appalachian coal mines have gradually moved into areas which are more difficult to mine, which has had a significant negative impact on productivity (Kuykendall and Qureshi, 2014: 3).

The Powder River Basin is relatively new and consists of large surface mines. While surface coal mining productivity in the Powder River Basin remains an order of magnitude higher than in Central Appalachia, it has declined by 28 per cent from its peak of 42,01 tons per employee hour in 2001 to 30,05 tons per employee hour in 2013 (Kuykendall and Qureshi, 2014: 1). The decline indicates that for surface mines in the Powder River Basin, opportunities for increased economies of scale and technological advances had mostly been exhausted by the early 2000s (Kuykendall and Qureshi, 2014: 2).

The Illinois Basin, in contrast, has maintained surface coal mining productivity at 1999 peak levels of between 5 and 6 tons per employee hour throughout the 2000s. While underground productivity slowed down between 1999 and 2009, it had recovered to 1999 peak levels of around 4,52 tons per employee hour by 2013 (Kuykendall and Qureshi, 2014: 1). This was accomplished through advancements in underground mining technology, most notably the re-introduction of longwall mining (Kuykendall and Qureshi, 2014: 4).

[16] Short tons.

Kuykendall and Qureshi (2014: 5) note that US coal mining productivity is expected to further improve over time as the most inefficient mines are closed first in response to lower demand. The switching of coal supply away from the Central Appalachian basin towards the more productive Illinois and Power River Basins is expected to continue, which will further boost productivity. The turnaround in labour productivity since 2012, as shown in **Chapter 6.3,** provides evidence in support of this prediction.

6.4.2 Australian coal mining productivity in the 2000s

The scholarly literature on Australian coal mining productivity provides more coverage compared to the US, with analyses extending until 2006/07. As noted in **Chapter 2.4**, both investment lags and resource depletion appear to have played a role in the productivity slowdown in the Australian coal mining sector since the 2000s. Other explanations for deteriorating productivity which have been offered, but not empirically tested, include a growing overburden ratio, regulatory changes, skills shortages, delays in equipment delivery and adverse weather conditions.

6.4.3 Global mining productivity in the 2000s

EY (2014) examines the productivity slowdown in the global mining sector since the 2000s. Although it does not include separate coverage of the coal mining industry, it provides a unique perspective on the underlying causes of the productivity slowdown in the form of a global survey of more than 60 senior mining executives. Survey participants were asked to provide their opinion regarding the causes of the productivity slowdown based on their experience within their organisation (EY, 2014: 3).

The survey highlights deteriorating worker quality as a key determinant of the productivity slowdown (EY, 2014: 3-4). Worker quality deteriorated during the mining boom of the early 2000s due to a number factors. With the rapid expansion of the mining industry, induction and training programmes were curtailed to bring new employees into the productive environment sooner. The large number of new employees, coupled with an ageing workforce, reduced the overall level of experience and managerial, technical and operational expertise in the mining industry.

The skills shortage was exacerbated by high employee turnover resulting from intense competition between mining companies to attract and retain skilled employees. The lack of skills and experience in the mining industry had knock-on effect on capital productivity, resulting in lower equipment utilisation levels (EY, 2014: 4; 11).

At the same time that worker quality was deteriorating, there was a significant expansion in mining activities. Mines were becoming larger and more complex with the emergence of the so-called “mega mine”. Inexperienced mine managers were ill-equipped to manage the increased complexity and productivity was negatively impacted resulting in diseconomies of scale (EY, 2014: 5).

Survey participants also highlighted a slowdown in innovation within the mining industry over the last few decades, which in the face of a deteriorating reserve base led to lower productivity (EY, 2014: 4-5).

6.5 Summary of global trends and explanations

The evidence reviewed in **Chapter 6** indicates that SA, the US and Australia experienced similar trends in coal mining productivity in the 2000s, with a marked slowdown in productivity until 2012 and signs of a turnaround in 2013 and 2014. SA coal mining productivity remained at levels between 30 and 40 per cent of its peers throughout the period. While this is indicative of structural differences between SA as a developing country and its counterparts in the developed world, it also points to the potential for SA to “catch up” to higher levels of productivity in future.

A review of the literature revealed a number of possible explanations for the global productivity slowdown in the 2000s, many of which are interlinked:

- **Resource depletion, technology and innovation:** In the 1980s and 1990s, technological advances compensated for deteriorating reserve quality, resulting in higher productivity. By the early 2000s, however, opportunities for productivity improvement had largely been exhausted. At the same time, mining companies have reduced innovation spending and fallen behind in developing new mining technology. In some instances, for example in the US, reserve depletion is expected to be mitigated by geographical shifts away from older, mined out reserve areas to newer, less geologically challenging reserve areas.
- **Investment lags:** The timing difference between initial capital investment and mines reaching full production explains at least a portion of deteriorating productivity in the US and Australia. As such, productivity is expected to recover in the near term as new mines reach full capacity and are debottlenecked.
- **Deteriorating worker quality:** The mining boom of the 2000s, coupled with an ageing workforce, resulted in a loss of skills and experience in the coal mining industry. The deterioration in worker quality had a further negative effect on equipment utilisation and capital productivity.
- **Increased complexity:** Mining operations have increased considerably in scale as new mines seek to exploit economies of scale. However, with greater size comes greater complexity and new, inexperienced managers were ill-equipped to deal with these challenges.

7 CONCLUSION

The report used publicly available data to assess trends in productivity in the SA coal mining industry since the 1980s and to compare SA's productivity performance since the 2000s with that of the US and Australia. The report has aimed to answer the following research questions:

- How should productivity be measured, what data are currently available to assess productivity performance and what are the shortcomings and measurement issues relating to SA mining productivity data?
- What has happened to productivity in the SA coal mining sector since the 1980s and how does SA coal mining productivity compare globally, in particular to developed countries with established coal mining sectors such as Australia and the US?
- What are the key drivers of productivity in the SA coal mining sector?
- How can the SA coal mining sector improve future productivity?

7.1 Measurement of SA coal mining productivity

The report highlighted some of the shortcomings of publicly available data for the SA coal mining industry:

- While data on the number of employees provides a simple, easy-to-interpret measure of labour input, data on hours worked remains a preferable measure. The number of employees does not capture changes in working hours over time, which is likely to have had a significant influence on productivity in SA. Similarly, working hours differ significantly between countries due to different legal and regulatory frameworks and employment practices. As such, hours worked data is a preferable measure for comparison between countries.

- It is difficult to disentangle the relative contributions of resource depletion, technological advances and investment lags on coal mining productivity in the absence of publicly available microdata at individual mine level. While the DMR collects detailed data on individual mine level, for confidentiality reasons information is currently only made available on an aggregated level.

7.2 Trends in SA coal mining productivity

The report identified the following trends in SA coal mining productivity:

- Between 1980 and 2003, productivity growth in the SA coal mining sector was primarily driven by capital deepening. Productivity growth was particularly strong in the early 1990s, reflecting labour shedding in the sector.
- Productivity growth has been negative from 2004 onwards, despite continued capital deepening. As a result of labour productivity declining at the same time that capital intensity was growing, TFP growth was also negative in this period.

The comparison of SA labour productivity with trends in the US and Australia found that:

- The three countries experienced similar trends in coal mining productivity in the 2000s, with a marked slowdown in productivity from 2007 until 2012, but signs of a turnaround in 2013 and 2014.
- SA coal mining productivity remained at levels between 30 and 40 per cent of its peers, pointing to the potential for SA to “catch up” to higher levels of productivity in future.

7.3 Key drivers of SA coal mining productivity

A number of possible explanations for declining productivity since the 2000s were identified:

- **Resource depletion, technology and innovation:** By the early 2000s, opportunities for productivity improvement through existing technology had largely been exhausted, so that the effects of resource depletion would have resulted in lower productivity. At the same time, mining companies have reduced innovation spending and fallen behind in developing new mining technology.
- **Investment lags:** The timing difference between initial capital investment and mines reaching full production explains at least a portion of deteriorating productivity. As such, productivity is expected to recover in the near term as new mines reach full capacity and are debottlenecked during the first few years of new mines being commissioned, typically between three to five years.
- **Deteriorating worker quality:** The global coal mining industry experienced a shortage of skills during the mining boom of the 2000s, as mining operations expanded globally without an accompanying expansion in skilled labour. The deterioration in worker quality had a further negative effect on equipment utilisation and capital productivity.
- **Increased complexity:** The greater scale of mining operations introduced greater complexity and new, inexperienced managers were ill-equipped to deal with these challenges.
- Other factors which may have led to deteriorating productivity in the 2000s include more stringent safety regulations and adverse labour market conditions, such as increased incidence of strikes.

7.4 Recommendations to improve productivity

In order to address declining productivity performance in the SA coal mining sector, the findings in this report point to the following:

- Although there may be some opportunity for SA coal mining operations to catch up to global productivity levels through increased scale or mechanisation, the international experience, especially since the 2000s, shows that capital effectiveness is also dependent on the quality of labour.
- Skills development is critical in order to make up for skills shortages and for SA to catch up to the productivity levels of its peers. The SA mining industry lost many skilled managers and operators to other more attractive jurisdictions abroad during the boom period and should consider measures to regain some of this valuable experience, for example by re-contracting with retired employees.
- The mining industry has fallen behind in investment in innovation and new technology to counteract the effects of resource depletion. In order to boost future productivity, there needs to be a coordinated effort by the mining industry, both at a corporate and government level, to invest in research and encourage innovation.

7.5 Recommendations for future work

Future studies of SA coal mining productivity should consider the following:

- The report recommends further investigation to establish the reason for the high correlation between shifts worked and the number of employees in the DMR data as a starting point to derive a useful measure of hours worked for the SA mining industry.

- One possible solution to address confidentiality concerns around the detailed individual mine level data which is collected by the DMR could be to provide access to the full disaggregated dataset to accredited researchers through a secure data repository, which will allow for the identification of the relative contributions of resource depletion, technological advances and investment lags on coal mining productivity.

Coal remains an important mineral commodity for the SA economy. Addressing declining productivity in the SA coal mining industry has the potential to improve mining companies' profitability, to generate increased tax revenues for government and to provide employment and economic development for local communities, overall ensuring that we make the best possible use of SA's mineral wealth.

REFERENCES

Australian Department of Industry, Innovation and Science, 2016a. *Australian Energy Update*, Australian Government, Department of Industry, Innovation and Science, Canberra [online]. Available at: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aes/2016-australian-energy-statistics.pdf (Accessed 21 December 2016).

Australian Department of Industry, Innovation and Science, 2016b. *Resources and Energy Quarterly*, data file, Australian Government, Department of Industry, Innovation and Science, Canberra [online]. Available at: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/ Resources-and-energy-quarterly.aspx# (Accessed 21 December 2016).

Bartelsman, E.J., and Doms, M., 2000. "Understanding Productivity: Lessons from Longitudinal Microdata", *Journal of Economic Literature*, XXXVIII (September 2000): 569-594.

Bureau of Resources and Energy Economics (BREE), 2014. *Australian Energy Update*, Australian Government, Bureau of Resources and Energy Economics, Canberra, [online]. Available at: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aes/2014-australian-energy-statistics.pdf (Accessed 23 December 2016).

DataFirst, 2012. *DataFirst's Secure Research Data Centre: Providing Researchers Access to Sensitive Information while Maintaining Confidentiality*, Cape Town: DataFirst, University of Cape Town, [online]. Available at: https://www.datafirst.uct.ac.za/documentation/13-sds-brochure/file (Accessed 9 January 2017).

DataFirst, 2013. *DataFirst Secure Data Service Procedures Manual*, Cape Town: DataFirst, University of Cape Town, [online]. Available at:

https://www.datafirst.uct.ac.za/images/docs/sds02-procedures-manual.pdf (Accessed 9 January 2017).

Deloitte, 2013. *Tracking the trends 2014: the top 10 issues mining companies will face in the coming year*, Deloitte Global Services Limited, [online]. Available at: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/dttl-er-Tracking-the-trends-2014_EN_final.pdf (Accessed 9 January 2017).

Department of Mineral Resources (DMR), 2015. *Production summary report* and *Labour summary for average employees at work*, unpublished data files, Pretoria: Department of Mineral Resources.

Eberhard, A., 2011. *The future of South African coal: market, investment and policy challenges*, Working Paper No 100, Programme on Energy and Sustainable Development, Stanford University, [online]. Available at: http://iis-db.stanford.edu/pubs/23082/WP_100_Eberhard_Future_of_South_African_Coal.pdf (Accessed 8 March 2016).

Eichengreen, B., Park, D., Shin, K., 2015. *The global productivity slump: common and country-specific factors*, NBER Working Paper No. 21556, September 2015, [online]. Available at: http://www.nber.org/papers/w21556 (Accessed 24 August 2017).

Ellerman, A.D., Stoker, T.M., Berndt, E., 2001. Sources of productivity growth in the American coal industry: 1972–1995. In: Dean, E., Harper, M., Hulten, C. (Eds.), *New Directions in Productivity Analysis*, National Bureau of Economic Research, University of Chicago Press, Chicago: 373-418, [online]. Available at: http://www.nber.org/chapters/c10130 (Accessed 30 January 2015).

Ernst & Young (EY), 2014. *Productivity in mining: now comes the hard part*, Ernst & Young, [online]. Available at: http://www.ey.com/Publication/EY-productivity-in-mining-now-comes-the-hard-part/$FILE/EY-productivity-in-mining-now-comes-the-hard-part.pdf (Accessed 6 May 2015).

Ernst & Young (EY), 2016. *Top 10 business risks facing mining and metals, 2016–2017*, Ernst & Young, [online]. Available at: http://www.ey.com/Publication/vwLUAssets/EY-business-risks-in-mining-and-metals-2016-2017/$FILE/EY-business-risks-in-mining-and-metals-2016-2017.pdf (Accessed 31 August 2017).

Eskom Holdings SOC Limited (Eskom), 2014. *Integrated report for the year ended 31 March 2014*, [online]. Available at: http://integratedreport.eskom.co.za/dow-pdf.php (Accessed 8 March 2016).

Eskom Holdings SOC Limited (Eskom), 2017. *Integrated report for the year ended 31 March 2017*, [online]. Available at: http://www.eskom.co.za/IR2017/Documents/Eskom_integrated_report_2017.pdf (Accessed 31 August 2017).

Eskom Holdings SOC Limited (Eskom), n.d. *Power stations and pumped storage schemes*, [online]. Available at: http://www.eskom.co.za/Whatwere doing/ElectricityGeneration/PowerStations/Pages/Power_Stations_And_Pumped_Storage_Schemes.aspx (Accessed 8 March 2016).

Fine, B., 1992. "Total Factor Productivity vs. Realism: The South African Coal Mining Industry", *South African Journal of Economics*, 60(3): 165-173.

Greene, W.H., 2003. *Econometric analysis*. New Jersey: Prentice Hall.

Hardman, D.R., 1996. "Coal-mining productivity in South Africa compared with Australia and the USA", *The Journal of The Southern African Institute of Mining and Metallurgy*, December 1996: 297-301, [online]. Available at: http://www.saimm.co.za/Journal/v096n07p297.pdf (Accessed 25 January 2015).

International Labour Office (ILO), 2016. ILOSTAT Database (Geneva), [online]. Available at: http://www.ilo.org/ilostat/ (Accessed 30 June 2016).

Jones, R.A., 1983. "Mechanization, Learning Periods, and Productivity Change in the South African Coal Mining Industry: 1950-80", *South African Journal of Economics*, 51(4): 342-351.

Krugman, P., 1990. *The Age of Diminished Expectations*. Reprint, Cambridge: MIT Press, 1997.

Kuykendall, T., and Qureshi, R., 2014. *US coal industry challenged by over a decade of declining productivity*, 6 March 2014, SNL Data Dispatch, SNL Financial, [online]. Available at: http://www.wvpolicy.org/wp-content/ uploads/ 2014/10/snlpdf_448ee5a0-d91f-447d-aa69-32d27d883b59.pdf (Accessed 4 January 2017).

Lovell, C.A.K., and Lovell, J.E., 2013. "Productivity decline in Australian coal mining", *Journal of Productivity Analysis* (2013) 40: 443-455.

McKinsey Metals & Mining Practice, 2015. *Downsizing the US coal industry: Can a slow-motion train wreck be avoided?*, November 2015, McKinsey & Company [online]. Available at: http://www.mckinsey.com/~/media/ McKinsey/Industries/Metals%20and%20Mining/Our%20Insights/Downsizing%20the%20US%20coal%20industry/Downsizing%20the%20US%20coal%20industry.ashx (Accessed 23 December 2016).

Mohring, R., 2012. *Proceedings of the 115th Annual General Meeting of The Southern African Institute of Mining and Metallurgy*: 787-798, [online]. Available at: http://www.saimm.co.za/Journal/v112n09p787.pdf (Accessed 22 January 2015).

Moolman, C.J. and Fourie, G.A., 2000. *Task 3.14.1: Evaluation of stripping techniques*, Coaltech 2020, [online]. Available at: http://www.coaltech.co.za/chamber 20databases 5Ccoaltech 5CCom_DocMan.nsf/0/1F874CB903D1627342257403002B6E93/$File/Task 203.14.1 20- 20Evaluation 20of 20Stripping.pdf (Accessed 25 January 2015).

Mudd, G.M., 2007. *The Sustainability of Mining in Australia: Key Production Trends and Their Environmental Implications for the Future*, Research Report No. RR5, Department of Civil Engineering, Monash University and Mineral Policy Institute, October, [online]. Available at: http://users.monash.edu.au/~gmudd/files/SustMining-Aust-Report-2009-Master.pdf (Accessed 30 January 2015).

OECD, 2001. Statistics portal: Glossary of statistical terms: Gross Value Added, [online]. Available at: https://stats.oecd.org/glossary/detail.asp?ID=1184 (Accessed 31 August 2017).

Peatfield, D., 2003. "Coal and coal preparation in South Africa – A 2002 review", *Journal of The South African Institute of Mining and Metallurgy*, July/August 2003: 355-372, [online]. Available at: http://www.saimm.co.za/ Journal/v103n06p355.pdf (Accessed 3 June 2016).

PricewaterhouseCoopers (PwC), 2014. *Mine 2014: Realigning expectations*, PricewaterhouseCoopers, [online]. Available at: http://www.pwc.com/en_ GX/gx/mining/publications/assets/pwc-mine-2014-realigning-expectations. pdf (Accessed 30 January 2015).

Quantec Research (Pty) Ltd (Quantec), 2015. *South African Standardised Industry Indicator Database, Sources and Description*, [online]. Available at: http://0-www.easydata.co.za.innopac.wits.ac.za/documents/ download/1489/ (Accessed 15 January 2016).

Richards Bay Coal Terminal (RBCT), n.d. *Our History*, [online]. Available at: http://www.rbct.co.za/about-rbct-4/our-history/ (Accessed 8 March 2016).

Sasol Limited (Sasol), 2014. *Committed to Southern Africa's advancement: A new era for Sasol*, November 2014, [online]. Available at: http://www.sasol.com/extras/sasol_sd/docs/sd_blocks/committed_to_Southern_Africa.pdf (Accessed 31 August 2017).

Schreyer, P., and Pilat, D., 2001. "Measuring Productivity", *OECD Economic Studies* (33)2001/II: 127-170, [online]. Available at: http://www.oecd.org/ eco/growth/1959006.pdf (Accessed 29 January 2015).

Seccombe, A., 2015. Safety stoppage costs bite miners. Business Day, [online], 21 September 2015. Available at: http://www.bdlive.co.za/ business/mining/2015/09/21/safety-stoppage-costs-bite-miners (Accessed 23 June 2016).

Solow, R.M., 1957. "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics*, 39: 312-320.

Spandau, A., 1980. "Mechanization and Labour Policies on South African Mines", *South African Journal of Economics*, 48(2): 110-120.

Statistics South Africa, 2014. *Youth employment, unemployment, skills and economic growth: 1994-2014*, [online]. Available at: http://beta2.statssa.gov.za/presentation/Youth 20employement, 20skills 20and 20economic 20growth 201994-2014.pdf (Accessed 9 April 2016).

Steindel, C., and Stiroh, K.J., 2001. *Productivity: What Is It, and Why Do We Care About It?*, April 2001, FRB of New York Staff Report No. 122, [online]. Available at: https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr122.pdf (Accessed 31 August 2017).

Stoker, T.M., Berndt, E.R., Ellerman, A.D., and Schennach, S.M., 2005. "Panel data analysis of U.S. coal productivity", *Journal of Econometrics* (127) 2005: 131–164.

Syverson, C., 2011. "What Determines Productivity?", *Journal of Economic Literature* (49)2: 326–365, [online]. Available at: http:www.aeaweb.org/ articles.php?doi=10.1257/jel.49.2.326 (Accessed 29 January 2015).

Takahashi, S., 2011. "How multi-tasking job designs affect productivity: Evidence from the Australian coal mining industry", *Industrial and Labor Relations Review*, 64(5): 841-862.

Tilton, J.E., 2014. "Cyclical and secular determinants of productivity in the copper, aluminum, iron ore, and coal industries", *Mineral Economics* (2014) 27: 1-19.

Tipper, A. and Warmke, N., 2012. *Adjusting productivity statistics for variable capacity utilisation: Working harder or hardly working?*, Statistics New Zealand Working Paper No 12–02, [online]. Available at: http://www.stats.govt.nz/~/media/Statistics/surveys-and-methods/methods/ research-papers/working-papers/Adjust-productivity-statisticsworking 20 paper.pdf (Accessed 28 January 2015).

Topp, V., Soames, L., Parham, D. and Bloch, H., 2008. *Productivity in the Mining Industry: Measurement and Interpretation*, Productivity Commission Staff Working Paper, December, [online]. Available at: http://www.pc.gov. au/research/completed/mining-productivity/mining-productivity.pdf (Accessed 28 January 2015).

US Bureau of Labour Statistics (US BLS), n.d. *Handbook of Methods, Chapter 11, Industry productivity measures*, [online]. Available at: https://www.bls.gov/ opub/hom/pdf/homch11.pdf (Accessed 22 December 2016).

US Energy Information Administration (US EIA), 2016. Coal Data Browser, [online]. Available at: http://www.eia.gov/beta/coal/data/browser/#/topic/33? agg=1 (Accessed 21 December 2016).

Van Ark, B., 1996. Issues in Measurement and International Comparison of Productivity – An Overview. In: OECD, *Industry Productivity – International Comparison and Measurement Issues*, Paris: 19-47.

Van Ark, B., 2014. *Total factor productivity: Lessons from the past and directions for the future*, National Bank of Belgium Working Paper

Research, October 2014, No 271, [online]. Available at: https://www.nbb.be/doc/ts/ publications/wp/wp271en.pdf (Accessed 23 August 2016).

APPENDIX A: STATA CODE TO GENERATE DATA

```
clear

version 13

set more off

set scheme s1manual


log using "C:\Current backups\Working folders\Persoonlik\Further
  studies\Wits\RESEARCH PROJECT\2016.12_final final
  report\logfile_productivity_annual.txt",            ///
  text replace


* Data input


import excel using "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\2017.01_data for
  stata.xlsx",    ///
  sheet(DATA) cellrange(A4) firstrow clear


ren Year t


format t %ty


sort t

tsset t


* Create input variables
```

```
gen hrs_tot = SHIFTS_TOT * 2200

gen hrs_tot_mil = hrs_tot / 1000000

gen hrs_tot_mil_ind05 = hrs_tot_mil / 122.5825 * 100

gen hrs_tot_empl = hrs_tot / EMPL_TOTAL


gen shifts_own = SHIFTS_EST_UG + SHIFTS_EST_S + SHIFTS_EST_OC

gen shifts_con = SHIFTS_CON_UG + SHIFTS_CON_S + SHIFTS_CON_OC

gen shifts_tot_thou = SHIFTS_TOT / 1000


gen hrs_own_mil = shifts_own * 2200 / 1000000

gen hrs_con_mil = shifts_con * 2200 / 1000000


gen empl_thou = EMPL_TOTAL / 1000

gen empl_thou_ind05 = empl_thou / 56.971 * 100

gen empl_thou_ind00 = empl_thou / 51.346 * 100


gen fcs_thoumil = FCAPS_CONS / 1000

gen fcs_thoumil_ind05 = fcs_thoumil / 74.2836 * 100

gen fcs_thoumil_ind00 = fcs_thoumil / 69.1745 * 100


gen pct_shifts_ug = SHIFTS_TOT_UG / SHIFTS_TOT * 100

gen pct_shifts_s = SHIFTS_TOT_S     / SHIFTS_TOT * 100

gen pct_shifts_oc = SHIFTS_TOT_OC / SHIFTS_TOT * 100



* Create output, price and exchange rate variables
```

```
gen loc_tons_mil = LOCSALT_TOT / 1000000

gen ex_tons_mil = EXSALT_TOT / 1000000

gen tons_mil = ROMT_TOT / 1000000

gen gva_cons_mil = GVA_CONS / 1000

gen tons_mil_ug = ROMT_UG / 1000000

gen tons_mil_oc = ROMT_OC / 1000000


gen tons_mil_ind00 = tons_mil / 2.2490677

gen gva_cons_mil_ind00 = gva_cons_mil / 43.0302 * 100

gen tons_mil_ind80 = tons_mil /  115.038246

gen gva_cons_mil_ind80 = gva_cons_mil / 23.155


gen exrate_ind00 = EXRATE / 6.9468


*------------------------------------------------------------------
  ----------------------------------------------*


* Chapter 5 - Descriptive analysis


** 5.1  Output measures


*** Figure 5.1 Saleable production tonnes: 1980 to 2014


twoway (tsline tons_mil loc_tons_mil ex_tons_mil if tin(1980,
  2014), ///

  clpattern(solid dash shortdash)),       ///

  ytitle(Million tonnes) ttitle(Year)                ///
```

```
  legend(label(1 "Saleable production tonnes") label(2 "Domestic
  sales tonnes") ///
  label(3 "Export sales tonnes")) ///
  ylabel(#8) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
  caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig5_1.emf", replace

*** Figure 5.2 Saleable production tonnes and GVA: 1980 to 2014

twoway (tsline tons_mil_ind00 gva_cons_mil_ind00 if tin(1980,
  2014), ///
  clpattern(solid dash)),     ///
  ytitle(Index (2000=100)) ttitle(Year)              ///
  legend(label(1 "Saleable production tonnes") label(2 "Gross
  Value Added")) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
  caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig5_2.emf", replace

*** Table 5.1 Correlation coefficients for GVA and saleable
  production
```

```
correlate tons_mil gva_cons_mil if tin(1980, 2014)

correlate tons_mil gva_cons_mil if tin(1980, 1992)

correlate tons_mil gva_cons_mil if tin(1993, 2014)


** 5.2 Input measures


*** Figure 5.3 Number of employees: 1980 to 2014


twoway (tsline empl_thou if tin(1980, 2014), ///
  clpattern(solid)),    ///
  ytitle(Number of employees ('000)) ttitle(Year)
      ///
  legend(label(1 "Number of employees")) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014)  ///
  caption(Source: Quantec (2015), size(small) position(7))


graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig5_3.emf", replace


*** Figure 5.4 Number of employees, shifts worked and hours
  worked: 2005 to 2014


twoway (tsline empl_thou shifts_tot_thou, yaxis(1) clpattern(solid
  dash)) ///
  (tsline hrs_tot_mil, yaxis(2) clpattern(shortdash)) ///
  if tin(2005, 2014), ///
```

```
  ytitle("No of employees / Average shifts worked" "(thousands)",
  axis(1)) ytitle(Average hours worked (millions), axis(2)) ///
  ttitle(Year)                ///
  legend(label(1 "No of employees") label(2 "Average shifts
  worked") ///
  label(3 "Average hrs worked")) ///
  tlabel(2005 2006 2007 2008 2009 2010 2011 2012 2013 2014) ///
  caption(Source: Quantec (2015); DMR (2015), size(small)
  position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig5_4.emf", replace



*** Correlation: Shifts worked and number of employees


correlate empl_thou SHIFTS_TOT hrs_tot_mil if tin(2005, 2014)


*** Figure 5.5 Fixed capital stock: 1980 to 2014


twoway (tsline fcs_thoumil if tin(1980, 2014), ///
  clpattern(solid)),    ///
  ytitle("Fixed capital stock" "R thousand millions at constant
  2010 prices", size(medsmall)) ttitle(Year)    ///
  ylabel(#8) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
  caption(Source: Quantec (2015), size(small) position(7))
```

```
graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig5_5.emf", replace

** 5.3 Comparison of output and input measures

*** Figure 5.6 Number of employees, fixed capital stock and
  saleable production: 1980 to 2014

twoway (tsline empl_thou_ind00 fcs_thoumil_ind00 tons_mil_ind00 if
  tin(1980, 2014), ///
  clpattern(solid dash shortdash)),       ///
  ytitle(Index (2000=100)) ttitle(Year)               ///
  legend(label(1 "Number of employees") label(2 "Fixed capital
  stock") ///
  label(3 "Saleable production tonnes")) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
  caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig5_6.emf", replace

** 5.4 Skills composition of the labour force

*** Figure 5.7 Number of employees by skills level: 1980 to 2014

gen empl_tot_thou = EMPL_TOTAL / 1000
```

```
gen empl_hskill_thou = EMPL_HSKILL / 1000

gen empl_skill_thou = EMPL_SKILL / 1000

gen empl_sskill_thou = EMPL_SSKILL / 1000


twoway (tsline empl_tot_thou empl_hskill_thou empl_skill_thou
  empl_sskill_thou if tin(1980, 2014), ///
  clpattern(solid dash shortdash longdash)),    ///
  ytitle(Number of employees (thousands)) ttitle(Year)      ///
  legend(label(1 "Total") label(2 "Highly skilled") ///
  label(3 "Skilled") label(4 "Semi- and unskilled")) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014)  ///
  caption(Source: Quantec (2015), size(small) position(7))


graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig5_7.emf", replace


** 5.5 Trends in mining methods


*** Figure 5.8 ROM production by mining method: 2006 to 2014


twoway (tsline tons_mil_ug tons_mil_oc if tin(2006, 2014), ///
  clpattern(solid dash)),     ///
  ytitle("Million tonnes ROM") ttitle(Year)     ///
  legend(label(1 "Underground production") label(2 "Opencast
  production")) ///
  tlabel(2006 2007 2008 2009 2010 2011 2012 2013 2014)  ///
  caption(Source: DMR (2015), size(small) position(7))
```

```
graph export "C:\Current backups\Working
   folders\Persoonlik\Further studies\Wits\RESEARCH
   PROJECT\2016.12_final final report\fig5_8.emf", replace


** 5.6 Trends in coal sales prices


*** Figure 5.9 Local and export sales prices and R/USD exchange
   rate


twoway (tsline PRICE_LOC_R PRICE_EXP_R, yaxis(1) clpattern(solid
   dash)) ///
   (tsline EXRATE, yaxis(2) clpattern(shortdash)) ///
   if tin(1980, 2014), ///
   ytitle(Rand per tonne (constant 2000 prices), axis(1)
   size(medsmall)) ytitle(Rand/US Dollar, axis(2) size(medsmall))
   ///
   ttitle(Year)  ///
   legend(label(1 "Unit sales price - local") label(2 "Unit sales
   price - export") ///
   label(3 "R/USD exchange rate")) ///
   tlabel(1980 1985 1990 1995 2000 2005 2010 2014)  ///
   caption("Source: Quantec (2015);
   http://www.federalreserve.gov/", size(small) position(7))


graph export "C:\Current backups\Working
   folders\Persoonlik\Further studies\Wits\RESEARCH
   PROJECT\2016.12_final final report\fig5_9.emf", replace
```

```
*----------------------------------------------------------------------
   --------------------------------------------*

* Chapter 6 - Trends in SA coal mining productivity

** Generate productivity measures  (Note: GVA_CONS and FCAPS_CONS
   in R million 2010 prices)

gen prod_tpe = ROMT_TOT / EMPL_TOTAL
gen prod_vape = GVA_CONS / EMPL_TOTAL * 1000
gen fcspe = FCAPS_CONS / EMPL_TOTAL * 1000
gen rempe = LREM_CONS / EMPL_TOTAL * 1000
gen prod_vape_sa = GVA_CONS_SA / EMPL_TOTAL_SA * 1000

* Growth rates of output (GVA and tonnes), labour and capital
gen gva_growth = ln(GVA_CONS / L.GVA_CONS)
gen tonnes_growth = ln(ROMT_TOT / L.ROMT_TOT)
gen labour_growth = ln(EMPL_TOTAL / L.EMPL_TOTAL)
gen fcs_growth = ln(FCAPS_CONS / L.FCAPS_CONS)
gen rem_growth = ln(LREM_CONS / L.LREM_CONS)

* Labour productivity growth
gen lprod_growth_gva = (gva_growth - labour_growth)
gen lprod_growth_tonnes = (tonnes_growth - labour_growth)

* Remuneration per employee growth
gen rempe_growth = (rem_growth - labour_growth)
```

```
* Weights and cost shares
gen s_lt = LREM_CURR / GVA_CURR
gen w_l = (s_lt + L.s_lt) / 2
gen w_k = 1 - w_l

* TFP growth (GVA and tonnes)
gen tfp_gva = gva_growth - (w_k * fcs_growth + w_l *
  labour_growth)
gen tfp_tonnes = tonnes_growth - (w_k * fcs_growth + w_l *
  labour_growth)

* Capital-labour ratio (changes)
gen kl_ratio = fcs_growth - labour_growth
gen kl_ratio_weighted = w_k * kl_ratio

* Create TFP indices by taking antilog and chaining(tonnes and
  GVA)

gen e_tfp_tonnes = exp(tfp_tonnes)
gen tfp_tonnes_00 = .
replace tfp_tonnes_00 = 100 if tin(2000, 2000)

foreach year of numlist 2001/2014 {
  replace tfp_tonnes_00 = e_tfp_tonnes * L.tfp_tonnes_00 if
  tin(`year', `year')
}
foreach year of numlist 1999/1980 {
```

```
  replace tfp_tonnes_00 = (1 / F.e_tfp_tonnes) * F.tfp_tonnes_00
  if tin(`year', `year')
}

gen e_tfp_gva = exp(tfp_gva)
gen tfp_gva_00 = .
replace tfp_gva_00 = 100 if tin(2000, 2000)

foreach year of numlist 2001/2014 {
  replace tfp_gva_00 = e_tfp_gva * L.tfp_gva_00 if tin(`year',
  `year')
}
foreach year of numlist 1999/1980 {
  replace tfp_gva_00 = (1 / F.e_tfp_gva) * F.tfp_gva_00 if
  tin(`year', `year')
}

* Create labour productivity indices by taking antilog and
  chaining (tonnes and GVA)

gen e_lprod_tonnes = exp(lprod_growth_tonnes)
gen lprod_tonnes_00 = .
replace lprod_tonnes_00 = 100 if tin(2000, 2000)

foreach year of numlist 2001/2014 {
  replace lprod_tonnes_00 = e_lprod_tonnes * L.lprod_tonnes_00 if
  tin(`year', `year')
}
```

```
foreach year of numlist 1999/1980 {
  replace lprod_tonnes_00 = (1 / F.e_lprod_tonnes) *
  F.lprod_tonnes_00 if tin(`year', `year')
}

gen e_lprod_gva = exp(lprod_growth_gva)
gen lprod_gva_00 = .
replace lprod_gva_00 = 100 if tin(2000, 2000)

foreach year of numlist 2001/2014 {
  replace lprod_gva_00 = e_lprod_gva * L.lprod_gva_00 if
  tin(`year', `year')
}
foreach year of numlist 1999/1980 {
  replace lprod_gva_00 = (1 / F.e_lprod_gva) * F.lprod_gva_00 if
  tin(`year', `year')
}

* Create capital-labour ratio indices by taking antilog and
  chaining

gen e_kl_ratio = exp(kl_ratio)
gen kl_ratio_00 = .
replace kl_ratio_00 = 100 if tin(2000, 2000)

foreach year of numlist 2001/2014 {
  replace kl_ratio_00 = e_kl_ratio * L.kl_ratio_00 if tin(`year',
  `year')
```

```
}

foreach year of numlist 1999/1980 {
    replace kl_ratio_00 = (1 / F.e_kl_ratio) * F.kl_ratio_00 if
    tin(`year', `year')
}


** 6.1 Labour productivity


*** Figure 6.1 Coal mining labour productivity - levels


twoway (tsline prod_tpe, yaxis(1) clpattern(solid)) ///
    (tsline prod_vape, yaxis(2) clpattern(dash)) ///
    if tin(1980, 2014), ///
    ytitle(Saleable tonnes, axis(1) size(medsmall)) ytitle("Gross
    Value Added" "(R thousands at constant 2010 prices)", axis(2)
    size(medsmall)) ///
    ttitle(Year)  ///
    legend(label(1 "Tonnes per employee") label(2 "GVA per
    employee")) ///
    tlabel(1980 1985 1990 1995 2000 2005 2010 2014)  ///
    caption(Source: Quantec (2015), size(small) position(7))


graph export "C:\Current backups\Working
    folders\Persoonlik\Further studies\Wits\RESEARCH
    PROJECT\2016.12_final final report\fig6_1.emf", replace


*** Figure 6.2 Coal mining labour productivity growth (Note: 2000
    is used as base year)
```

```
twoway (tsline lprod_growth_tonnes lprod_growth_gva if tin(1980,
  2014), ///
  clpattern(solid dash)), ///
  ytitle("Growth rate") ttitle(Year) ///
  legend(label(1 "Tonnes per employee") label(2 "GVA per
  employee")) ///
  ylabel(#8) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
  caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig6_2.emf", replace

*** Correlation: GVA per worker (growth rate) and tonnes per
  worker (growth rate)

correlate lprod_growth_tonnes lprod_growth_gva if tin(1980, 2014)
correlate lprod_growth_tonnes lprod_growth_gva if tin(1980, 1992)
correlate lprod_growth_tonnes lprod_growth_gva if tin(1993, 2014)

*** Figure 6.3 Labour productivity - GVA and output for total
  economy

twoway (tsline prod_vape prod_vape_sa if tin(1980, 2014), ///
  clpattern(solid dash)), ///
  ytitle("GVA / Output per employee" "(R thousands at constant
  2010 prices)", size(medsmall)) ttitle(Year) ///
```

```
   legend(label(1 "Coal mining" "(GVA per employee)") label(2
   "Total economy" "(Output per employee)")) ///
   ylabel(#8) ///
   tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
   caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
   folders\Persoonlik\Further studies\Wits\RESEARCH
   PROJECT\2016.12_final final report\fig6_3.emf", replace

*** Table 6.1     Labour productivity - GVA and output for total
   economy

outsheet t prod_tpe prod_vape prod_vape_sa if tin(1980, 2014) ///
   using "C:\Current backups\Working folders\Persoonlik\Further
   studies\Wits\RESEARCH PROJECT\2016.12_final final
   report\lprod_coal_sa.csv", comma nolabel replace

** 6.2 Capital intensity

*** Figure 6.4  Capital stock per employee

twoway (tsline fcspe, yaxis(1) clpattern(solid)) ///
   (tsline kl_ratio, yaxis(2) clpattern(dash)) ///
   if tin(1980, 2014), ///
   ytitle("Fixed Capital Stock per employee" "(R thousands at
   constant 2010 prices)", axis(1) size(medsmall))
   ytitle(Percentage change, axis(2) size(medsmall)) ///
   ttitle(Year)  ///
```

```
  legend(label(1 "FCS per employee") label(2 "Change in FCS" "per
  employee")) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
  caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig6_4.emf", replace

** 6.3 Labour remuneration

*** Figure 6.5  Labour productivity and remuneration per employee

twoway (tsline rempe, yaxis(1) clpattern(solid)) ///
  (tsline prod_tpe, yaxis(2) clpattern(dash)) ///
  if tin(1980, 2014), ///
  ytitle("Remuneration per employee" "(R thousands at constant
  2010 prices)", axis(1) size(medsmall)) ytitle("Tonnes per
  employee", axis(2) size(medsmall)) ///
  ttitle(Year)  ///
  legend(label(1 "Remuneration" "per employee") label(2 "Tonnes"
  "per employee")) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014)  ///
  caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig6_5.emf", replace
```

```
*** Figure 6.6    Labour productivity and remuneration per
   employee (growth rates)

twoway (tsline rempe_growth lprod_growth_tonnes if tin(1980,
   2014), ///
   clpattern(solid dash)), ///
   ytitle("Growth rate") ttitle(Year) ///
   legend(label(1 "Remuneration" "per employee") label(2 "Tonnes"
   "per employee")) ///
   ylabel(#8) ///
   tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
   caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
   folders\Persoonlik\Further studies\Wits\RESEARCH
   PROJECT\2016.12_final final report\fig6_6.emf", replace

*** Table 6.2     Labour productivity, capital intensity and
   labour remuneration

list t prod_tpe fcspe rempe if tin(1980, 2014), clean nolabel
outsheet t prod_tpe fcspe rempe if tin(1980, 2014) ///
   using "C:\Current backups\Working folders\Persoonlik\Further
   studies\Wits\RESEARCH PROJECT\2016.12_final final
   report\tpe_fcspe_rempe.csv", comma nolabel replace

** 6.3 Total factor productivity

*** Figure 6.7 TFP growth based on GVA and saleable tonnes
```

```
twoway (tsline tfp_tonnes tfp_gva if tin(1980, 2014), ///
  clpattern(solid dash)), ///
  ytitle("Growth rate") ttitle(Year) ///
  legend(label(1 "TFP (based on tonnes)") label(2 "TFP (based on
  GVA)")) ///
  ylabel(#8) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014) ///
  caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig6_7.emf", replace

** 6.4 Decomposition of labour productivity growth

*** Figure 6.8  Labour productivity, TFP and capital intensity
  index

twoway (tsline tfp_tonnes_00 lprod_tonnes_00 kl_ratio_00 if
  tin(1980, 2014), ///
  clpattern(solid dash shortdash)), ///
  ytitle("Index (2000 = 100)") ttitle(Year)  ///
  legend(label(1 "TFP" "(tonnes-based)") label(2 "Labour
  productivity" "(tonnes-based)") ///
  label(3 "Capital-labour ratio")) ///
  ylabel(#8) ///
  tlabel(1980 1985 1990 1995 2000 2005 2010 2014)  ///
```

```
   caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
   folders\Persoonlik\Further studies\Wits\RESEARCH
   PROJECT\2016.12_final final report\fig6_8.emf", replace

***  Table 6.3  Decomposition of labour productivity growth into
   TFP growth and weighted capital-labour ratio

list t lprod_growth_tonnes tfp_tonnes kl_ratio_weighted
   tfp_tonnes_00 lprod_tonnes_00 kl_ratio_00 if tin(1980, 2014),
   clean nolabel
outsheet t lprod_growth_tonnes tfp_tonnes kl_ratio_weighted
   tfp_tonnes_00 lprod_tonnes_00 kl_ratio_00 if tin(1980, 2014)
   ///
   using "C:\Current backups\Working folders\Persoonlik\Further
   studies\Wits\RESEARCH PROJECT\2016.12_final final
   report\tfp.csv", comma nolabel replace

** 6.6 Other explanations for deteriorating productivity in the
   2000s

***  Figure 6.9

twoway (tsline STRIKE if tin(1998, 2014), ///
   clpattern(solid)),    ///
   ytitle(No of days not worked per 1000 workers, size(medsmall))
   ttitle(Year)    ///
   legend(label(1 "Workdays lost due to strike and lockouts
   (mining and quarrying)")) ///
```

```
  tlabel(#8)  ///
  caption(Source: Quantec (2015), size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig6_9.emf", replace

*-------------------------------------------------------------------
  -----------------------------------------------*

* Chapter 7 - Trends in SA coal mining productivity

** Generate comparison measures (levels)

gen tons_za = (ROMT_UG + ROMT_OC)
gen tons_mil_za = tons_za / 1000000
gen tons_mil_aus = ROMT_TOT_AUS / 1000000
gen tons_mil_us = ROMT_TOT_US / 1000000
gen empl_thou_aus = EMPL_TOT_AUS / 1000
gen empl_thou_us = EMPL_TOT_US / 1000

gen prod_tpe_za = (ROMT_UG + ROMT_OC) / EMPL_TOTAL
gen prod_tpe_aus = ROMT_TOT_AUS / EMPL_TOT_AUS
gen prod_tpe_us = ROMT_TOT_US / EMPL_TOT_US
gen prod_tpe_thou_za = prod_tpe_za / 1000
gen prod_tpe_thou_aus = prod_tpe_aus / 1000
gen prod_tpe_thou_us = prod_tpe_us / 1000
```

```
** Generate comparison measures (growth rates)

gen tonnes_growth_za = ln(tons_za / L.tons_za)
gen tonnes_growth_aus = ln(ROMT_TOT_AUS / L.ROMT_TOT_AUS)
gen labour_growth_aus = ln(EMPL_TOT_AUS / L.EMPL_TOT_AUS)
gen tonnes_growth_us = ln(ROMT_TOT_US / L.ROMT_TOT_US)
gen labour_growth_us = ln(EMPL_TOT_US / L.EMPL_TOT_US)
gen lprod_growth_za = (tonnes_growth_za - labour_growth)
gen lprod_growth_aus = (tonnes_growth_aus - labour_growth_aus)
gen lprod_growth_us = (tonnes_growth_us - labour_growth_us)

* Create labour productivity indices

gen lprod_za_07 = prod_tpe_za /  5167.497030063370000  * 100
gen lprod_aus_07 = prod_tpe_aus / 15433.6146142238 * 100
gen lprod_us_07 = prod_tpe_us / 12798.1648025109 *100
gen lprod_za_aus = prod_tpe_za / 15433.6146142238 * 100
gen lprod_us_aus = prod_tpe_us / 15433.6146142238 * 100

** 7.1 Production trends

*** Figure 7.1  SA, US and Australia total coal production (metric
  tonnes) : 2007-2014

twoway (tsline tons_mil_za tons_mil_aus tons_mil_us if tin(2007,
  2014), ///
  clpattern(solid dash shortdash)), ///
```

```
  ytitle("Total raw coal production" "Million tonnes (metric)")
  ttitle(Year)  ///
  legend(label(1 South Africa) label(2 Australia) ///
  label(3 United States)) ///
  ylabel(#6) ///
  tlabel(2007 2008 2009 2010 2011 2012 2013 2014)  ///
  caption("Source: DMR (2015); US EIA (2016); Australian
  Department of Industry," "Innovation and Science (2016)",
  size(small) position(7))

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\fig7_1.emf", replace

** 7.2 Employment trends

** Figure 7.2 SA, US and Australia employees : 2007-2014

twoway (tsline empl_thou empl_thou_aus empl_thou_us if tin(2007,
  2014), ///
  clpattern(solid dash shortdash)), ///
  ytitle("Total no of employees" "Thousands") ttitle(Year)  ///
  legend(label(1 South Africa) label(2 Australia) ///
  label(3 United States)) ///
  ylabel(#8) ///
  tlabel(2007 2008 2009 2010 2011 2012 2013 2014)  ///
  caption("Source: DMR (2015); US EIA (2016); Australian
  Department of Industry," "Innovation and Science (2016)",
  size(small) position(7))
```

```
graph export "C:\Current backups\Working
   folders\Persoonlik\Further studies\Wits\RESEARCH
   PROJECT\2016.12_final final report\fig7_2.emf", replace

** 7.3 Trends in output per employee (levels comparison)

** Figure 7.3 SA, US and Australia tonnes per employee : 2007-2014

twoway (tsline prod_tpe_thou_za prod_tpe_thou_aus prod_tpe_thou_us
   if tin(2007, 2014), ///
   clpattern(solid dash shortdash)), ///
   ytitle("Raw tonnes per employee" "Thousands") ttitle(Year)  ///
   legend(label(1 South Africa) label(2 Australia) ///
   label(3 United States)) ///
   ylabel(#8) ///
   tlabel(2007 2008 2009 2010 2011 2012 2013 2014)

graph export "C:\Current backups\Working
   folders\Persoonlik\Further studies\Wits\RESEARCH
   PROJECT\2016.12_final final
   report\tpe_comparison_international.tif", replace

** 7.4 Trends in labour productivity growth

twoway (tsline lprod_growth_za lprod_growth_aus lprod_growth_us if
   tin(2007, 2014), ///
   clpattern(solid dash shortdash)), ///
```

```
  ytitle("Raw tonnes per employee" "Growth rate") ttitle(Year)
  ///
  legend(label(1 South Africa) label(2 Australia) ///
  label(3 United States)) ///
  ylabel(#8) ///
  tlabel(2007 2008 2009 2010 2011 2012 2013 2014)

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final
  report\lprod_growth_international.tif", replace

** 7.5 Trends in labour productivity growth - indexed to 2007

twoway (tsline lprod_za_07 lprod_aus_07 lprod_us_07 if tin(2007,
  2014), ///
  clpattern(solid dash shortdash)), ///
  ytitle("Raw tonnes per employee" "Index 2000 = 100")
  ttitle(Year)  ///
  legend(label(1 South Africa) label(2 Australia) ///
  label(3 United States)) ///
  ylabel(#8) ///
  tlabel(2007 2008 2009 2010 2011 2012 2013 2014)

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\lprod_growth_2007
  index.tif", replace
```

```
** 7.6 Trends in labour productivity growth - Australia 2007 = 100

twoway (tsline lprod_za_aus lprod_aus_07 lprod_us_aus if tin(2007,
  2014), ///
  clpattern(solid dash shortdash)), ///
  ytitle("Raw tonnes per employee" "Australia 2007 = 100")
  ttitle(Year)  ///
  legend(label(1 South Africa) label(2 Australia) ///
  label(3 United States)) ///
  ylabel(#8) ///
  tlabel(2007 2008 2009 2010 2011 2012 2013 2014)

graph export "C:\Current backups\Working
  folders\Persoonlik\Further studies\Wits\RESEARCH
  PROJECT\2016.12_final final report\lprod_growth_aus index.tif",
  replace

log close
exit
```

APPENDIX B: KEY DATA GENERATED USING STATA CODE

t	prod_tpe	prod_vape	fcspe	rempe	lprod_growth_tonnes	tfp_tonnes	kl_ratio_weighted	tfp_tonnes_00	lprod_tonnes_00	kl_ratio_00
1980	898	181	175	114			0,041	67	21	13
1981	957	146	185	124	0,064	0,026	0,038	69	22	14
1982	1 096	147	213	134	0,136	0,048	0,088	72	25	16
1983	1 273	179	253	141	0,150	0,043	0,107	75	29	19
1984	1 386	191	256	146	0,085	0,077	0,007	81	32	19
1985	1 453	216	263	145	0,047	0,030	0,017	84	33	20
1986	1 471	247	278	150	0,012	-0,025	0,038	82	34	21
1987	1 545	207	303	152	0,049	-0,006	0,056	81	35	23
1988	1 667	236	336	158	0,076	0,014	0,062	82	38	25
1989	1 659	249	357	162	-0,005	-0,043	0,038	79	38	27
1990	1 686	293	398	174	0,016	-0,047	0,063	75	38	30
1991	1 855	303	484	177	0,096	-0,015	0,111	74	42	36
1992	2 332	441	685	197	0,229	0,041	0,188	77	53	51
1993	2 994	574	879	205	0,250	0,120	0,130	87	68	65
1994	3 264	625	981	206	0,086	0,027	0,059	90	75	73
1995	3 313	625	1 024	203	0,015	-0,010	0,025	89	76	76
1996	3 234	617	1 034	200	-0,024	-0,030	0,006	86	74	77
1997	3 559	675	1 077	205	0,096	0,071	0,025	92	81	80
1998	3 711	707	1 118	207	0,042	0,019	0,022	94	85	83
1999	4 014	769	1 229	212	0,079	0,024	0,054	96	92	91
2000	4 380	838	1 347	213	0,087	0,036	0,052	100	100	100
2001	4 405	853	1 389	209	0,006	-0,013	0,019	99	101	103
2002	4 640	899	1 526	210	0,052	-0,008	0,060	98	106	113

t	prod_tpe	prod_vape	fcspe	rempe	lprod_growth_tonnes	tfp_tonnes	kl_ratio_weighted	tfp_tonnes_00	lprod_tonnes_00	kl_ratio_00
2003	5 035	978	1 576	214	0,082	0,061	0,020	104	115	117
2004	4 900	942	1 485	214	-0,027	0,009	-0,036	105	112	110
2005	4 300	845	1 304	211	-0,131	-0,052	-0,079	100	98	97
2006	4 237	835	1 327	212	-0,015	-0,025	0,011	97	97	99
2007	4 098	811	1 346	211	-0,033	-0,041	0,008	93	94	100
2008	3 858	763	1 351	201	-0,060	-0,063	0,003	88	88	100
2009	3 540	698	1 355	198	-0,086	-0,088	0,002	80	81	101
2010	3 436	686	1 381	193	-0,030	-0,043	0,013	77	78	102
2011	3 196	632	1 388	187	-0,072	-0,076	0,004	71	73	103
2012	3 106	617	1 391	186	-0,029	-0,030	0,002	69	71	103
2013	2 922	581	1 390	188	-0,061	-0,060	-0,001	65	67	103
2014	3 034	577	1 488	188	0,037	-0,011	0,048	64	69	110